EDUCATION MANUAL

Elementary Meteorology

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PREFACE

The Importance of Meteorology. The place of meteorology in agriculture, industry, navigation, and transportation has long been recognized. Today the vast and various activities related to flying demand accurate up-to-the-minute information about the weather. The work of the professional meteorologist becomes of increasingly vital importance the more we utilize the air as a medium for transportation. For weather affects the performance of the airplane, its motor, propeller, and instruments. Having reliable meteorological information and knowing how to use it are primary factors in flying an airplane safely and efficiently.

There is no one of us who is not affected by the weather or who cannot profit by learning about the atmosphere and how it behaves. During the last several years great strides have been made in meteorology. This book introduces you to a science that has unlimited possibilities for development and for use.

How to Use This Book. This special edition of *Elementary Meteorology* has been prepared exclusively for off-duty group study by military personnel. A book on a scientific subject such as this is not like a magazine story. You must be sure you understand what you are reading. Even though you know the meaning of all the words, you may have to go over the text two or three times to get the idea. You will find that the more you study, the easier it is to study effectively.

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CONTENTS

ELEMENTARY METEOROLOGY

Chapter I. The Earth and Its Planetary Relations

The importance of science in modern life is recognized by nearly everyone. We can all think of numberless ways in which physics, mathematics, chemistry, biology, and other fields of scientific study have contributed to the richness and comfort of our surroundings and to the broadening of our general knowledge.

There was a time, in the early days of science, when the amount of scientific knowledge was so small that one well-educated man could profess to be master of all of it. That time is past. The growth of knowledge has added so much of special detail in each of the scientific fields that no one mind can understand the total. Today, to obtain a good knowledge of even one of the sciences may take more time than the average student has to give. Such detailed and technical knowledge is more useful in a professional career than in the general business of living.

However, some study of science is important for the understanding of life about us and for the kind of training that it gives. Science deals both with general ideas and with definite facts and their relation to one another. The mastery of any body of facts in the field of natural science requires the learning of many new terms and principles. Much more important, however, for the education of the student, is that it requires the constant use of reason. Facts in any field of learning cannot be fully understood by themselves. They can be understood only as they are related to other things. Reasoning helps us to appreciate that relationship.

Because modern science tends to be specialized, it is desirable that an introductory course in science involve at least some of the principles of several of the sciences. To be sure, each of the

scientific studies does this to some degree. Students of physics and chemistry cannot progress far without using mathematics. Neither can biologists nor geologists advance greatly in their fields of learning without applying the principles of chemistry and physics.

But there is one general field of scientific study in which, more than in any other, important principles from several of the sciences may be brought together and studied in their relationship to one another. That field may be called *earth science*. In it are combined facts from several related fields. There are the simple mathematical ideas relating to the earth as a planet and the means of picturing it in maps. There are the physical principles governing the climates of the earth's atmosphere. There are the processes by which the surface forms of the land are molded. There is the chemistry of rocks and soils. There are the biological relationships of the plants and animals that man uses in the process of getting a living.

Recent years have witnessed a considerable improvement in methods of transportation, which, together with the completion of thousands of miles of good roads, has resulted in increased travel by larger numbers of people. Their travels lead them to many interesting places, such as the ocean shore, the north woods, or regions of hills and mountains. In these various localities they observe the great variety of features of the earth's surface. One region may have many beautiful lakes; another may have none. One shoreline may be smooth and sandy; another, rocky and dangerous. Certain mountains may be rounded, smooth, and not difficult to climb, while others are rugged, steep, and so high that they are covered with snow and glaciers. A clear, sparkling mountain stream tumbling over numerous rapids and waterfalls contrasts sharply with the slow-moving, muddy creek of level lowlands. From place to place climatic conditions may vary considerably. A West-coast locality may have a fairly uniform, cool, foggy, rainy climate, while another region much farther inland may experience a great variety of weather changes, such as blizzards, hot waves, and droughts. A common topic of conversation is the condition of local weather, a knowledge of which is especially valuable to the farmer, the orchardist, the airplane pilot, and many others. Most of us have noticed

these variations in earth phenomena and have already become interested in the way in which they are related to land use and man's mode of living. Certainly a knowledge of at least some of them would contribute greatly to man's understanding of environmental conditions in different parts of the world. This book on earth science is an attempt to make such a contribution.

The Earth

Many familiar conditions, both in the realm of nature and in our everyday lives, have their origins in the shape and size of the earth and its relation to other heavenly bodies, especially the sun. Our common ideas of distance, area, direction, time, and weight depend upon these conditions of earth size and relation.

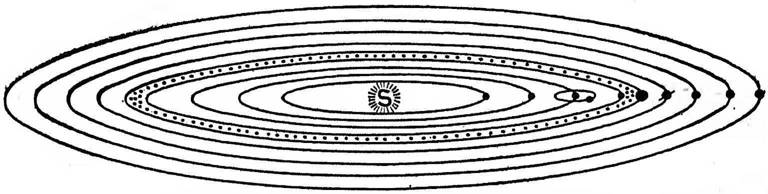

FIG. 1.—The planets move about the sun in orbits nearly spherical in shape. Mercury is nearest the sun; Venus comes second; then the earth, around which is shown the orbit of the moon. Next in order are Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. Revolving around the sun between the orbits of Mars and Jupiter are several hundred asteroids.

Such phenomena as day and night, the seasons, the tides of the ocean, and indeed the very existence of the oceans and the atmosphere depend upon them also. Knowledge of the external relations of the earth is important to an understanding of the nature of earth environment and of the ways in which natural features are related to those created by man.

The Earth in Space. The earth is a planet. It is a member of the solar system which consists of (1) the sun, which is a star and the center of the system; (2) nine planets and their satellites, all of which revolve around the sun; (3) several hundred asteroids, which are small planets; and (4) a few comets.

The planets in order from the sun are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. It should be remembered that the sun shines by its own light but the planets reflect the light of the sun (Fig. 1).

The earth's satellite, the moon, revolves around the earth about once a month (Fig. 2). Earth and moon travel together, making a complete trip around the sun once a year. Eclipses occur when the three bodies—sun, earth, and moon—are in a straight line. When the moon comes between the earth and the sun, an eclipse of the sun results. This can occur only at the new moon. When the earth is between the sun and the moon, an eclipse of the moon results. This can occur only at full moon. The distance from the earth to the moon is much less than the radius of the sun.

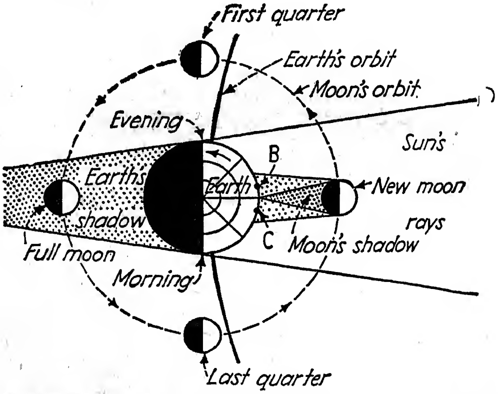

Fig. 2.—This diagram shows the phases of the moon and the eclipses. At the right the moon is in position for total eclipse of the sun, visible at the point where the moon's darker shadow reaches the earth. A partial eclipse would be observed at other points such as *B* and *C*. At the left of the diagram the moon is in the earth's shadow. When this occurs, an eclipse of the moon is observed from the earth.

Shape of the Earth. The earth is almost a sphere. A slight flattening at each earth pole causes the radius from the earth center to the pole to be about 13.5 miles shorter than the distance from the center to any point on the equator. That is the earth's greatest departure from being a true sphere. Great ocean deeps (6 miles or more below sea level) and high mountain peaks (5.5 miles above sea level) exist, but the height of the highest mountain above the lowest point on the ocean floor is not more than the amount of the polar flattening. If the circumference of the earth is represented by a true chalk circle of the largest size that can be drawn on an ordinary blackboard, the chalk line will have more than enough thickness to include all the earth's

departures from being a true sphere, if they could be represented properly at that scale.

Size of the Earth. The earth has a polar diameter of about 7,900 miles and an equatorial diameter about 27 miles greater. At the equator it lacks only 100 miles of being 25,000 miles in circumference. Its surface area is nearly 197 million square miles. The size of the earth is, therefore, great but not vast in comparison with some other heavenly bodies. The planet Jupiter, for example, has a diameter of over 80,000 miles.

Force of Gravity. Because of its great size and density (weight per unit volume) the earth has a strong attraction for objects on or near its surface. This attraction is called the *force of gravity.* It holds the atmosphere and hydrosphere (waters of the earth) on the earth's surface. It determines the weight of all objects. The force of gravity in fact holds the earth together and attracts all objects to it. Its constant presence is taken for granted by everyone. The pull of gravity enables builders to establish a vertical line (necessary in constructing walls of buildings) by means of a *plumb line* (a string to which a weight is attached). Such a line is perpendicular to a tangent to the earth's surface at the point where it touches. A line drawn perpendicularly to the tangent at some other point is not vertical (Fig. 3). The shadow of the plumb line at noon (sun time) establishes a true north-south direction.

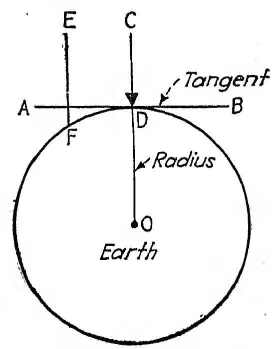

FIG. 3.—The line *CD* is the plumb line referred to in the text. Only such a line can be called vertical. The line *EF*, for example, although parallel to *CD*, is not vertical, for it does not form, with a radius, a straight line to the center of the earth.

Land, Water, and Air. The solid mass of the earth (the lithosphere) is covered in part by water (the hydrosphere). Both are surrounded by an envelope of gas (the atmosphere) which has a thickness of at least several scores of miles. Each of these "spheres" touches upon the life of man in many ways, and their many different features or phases combine and recombine in hundreds of ways to make up the sets of natural features that characterize different regions of the world.

Some of the combinations of hydrosphere and atmosphere form regions that are eminently suited to the habitation of man and to intensive use by modern human society. Others form regions that are very unsuited. In the latter group are the depressed parts of the earth crust which are occupied by oceans and the great seas. These together occupy about 71 per cent of the surface of the sphere, leaving the smaller part, about 29 per cent, as the exposed continental surfaces. Only these are in any degree suited to permanent human abode.

The total area of the land surface of the earth, about 51 million square miles, is equal to about seventeen times the area of the United States. Upon this rather restricted surface the entire human population of the earth resides and tries to secure a living. However, large parts of the land, for one reason or another, are poorly suited to human occupation or use. The primary purpose of this book is to direct attention to the many different phases of the major elements, land, water, and air, which combine to create the great variety of conditions under which men live.

Earth Motions

Earth Rotation and Its Consequences. The two principal motions of the earth are (1) rotation on its axis and (2) revolution around the sun. The earth rotates upon an imaginary axis which, because of the polar flattening, is its shortest diameter. The ends of the axis of rotation are at the earth poles. The time required for the earth to rotate once upon its axis is called a *day* and is divided into 24 hours.

During the period of one day each place on the sphere is turned alternately toward and away from the sun. Each experiences a period of light and a period of darkness. Each also has been swept over twice by the circle of illumination (the dividing line between day and night), once at dawn and again at twilight.

The direction of earth rotation is toward the east. This fact has broad significance. Not only does it determine the direction in which the sun, moon, and stars appear to rise and set. It is also related to other earth phenomena of far-reaching consequence, such as the prevailing directions of winds and ocean currents, which will be studied later.

Earth Revolution. The rotating earth revolves in a slightly elliptical orbit, or path, about the sun. It keeps an average distance from the sun of about 93 million miles (Fig. 4). It is held in its orbit by two forces, *viz.*, (1) the attraction of gravitation of the sun and (2) centrifugal force.

All heavenly bodies attract each other. The larger the body the stronger is its attraction. The sun is an enormous body, having a diameter of about 860,000 miles. The great size of the sun is largely responsible for its tremendous "attraction of

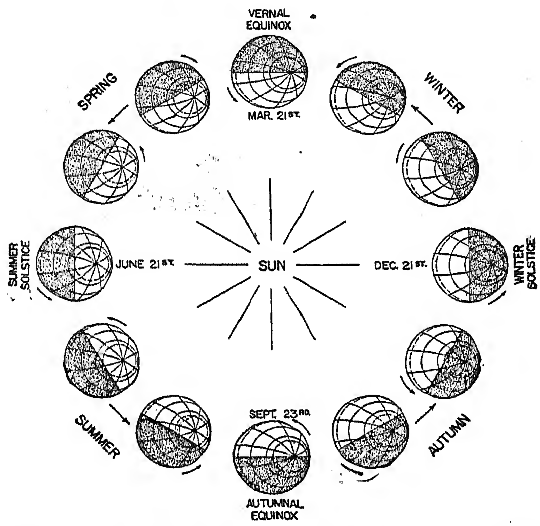

FIG. 4.—The relation of the inclination of the earth's axis to the change of seasons in the Northern Hemisphere (see Appendix A).

gravitation," which holds the various planets in their orbits. The attraction of gravitation of the earth holds the moon in its orbit and attracts meteors toward the earth. The meteors, wrongly called "shooting stars," burn because of friction with the earth's atmosphere caused by the terrific speed at which they are traveling (Fig. 5).

The speed of the earth as it travels through space is indeed great, being over 60,000 miles per hour. This speed tends to pull the earth away from the sun, like mud flying off a rotating wheel. The outward pull exerted by a rotating body is called *centrifugal force*. This force opposes the sun's attraction of gravitation. Here there is a continual struggle between two

great forces. The balance between them establishes the orbit over which the earth travels year after year.

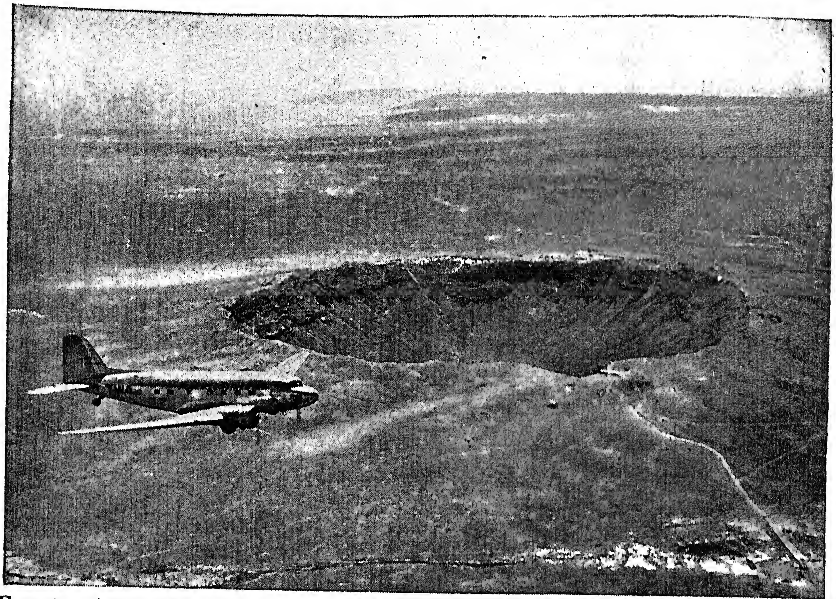

Fig. 5.—A meteor made this basin near Winslow, Ariz. The basin is nearly a mile in diameter and about 600 feet deep. (*Courtesy of Transcontinental and Western Air, Inc.*)

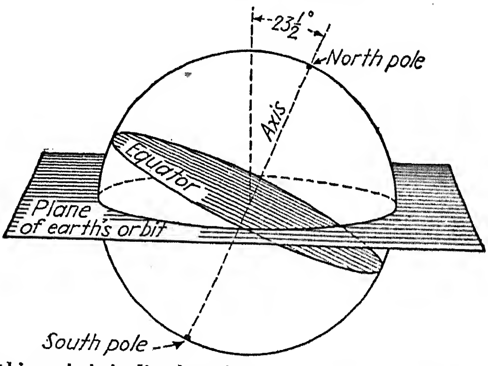

Fig. 6.—The earth's axis is inclined $23\frac{1}{2}°$ from a line perpendicular to the plane of the earth's orbit.

The time required for the earth to pass once completely around its orbit fixes the length of the year. During the time of one revolution the spinning earth rotates on its axis approximately $365\frac{1}{4}$ times, thus determining the number of days in the year.

An imaginary plane passed through the sun and extended outward through all points in the earth's orbit is called the *plane of the orbit.* The earth's axis has a fixed inclination of about $23\frac{1}{2}°$ from a line perpendicular to the plane of the orbit (Figs. 6, 7). This position is constant, with the North Pole always pointing toward the North Star. Therefore, the axis at any time during the yearly revolution is parallel to the position it occupied at any previous time. This is called the *parallelism of the axis.*

The degree of inclination of the earth's axis and its parallelism, together with the earth's shape, its rotation on its axis, and its revolution about the sun, combine to produce several earth phenomena which are of vital importance among the

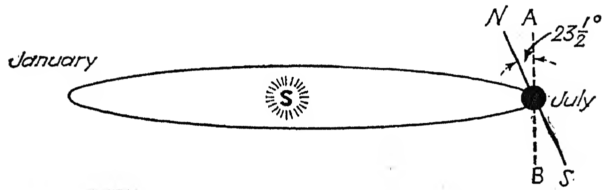

FIG. 7.—The sun, somewhat off center in the earth's orbit, is about 3 million miles closer to the earth in January than it is in July. Winter and summer climates are due to the inclination of the earth's axis *NS* and not to distance from the sun.

conditions that surround us. Some of these are (1) the primary distribution of the sun's heat and light over the earth, (2) the changing of the seasons, and (3) the changing lengths of day and night. These matters and others related to them will be discussed more fully in their connection with climate.

Location on the Earth

Earth Grid. The location of the North and South poles of the earth is established by rotation of the earth on its axis. With the poles as starting points, a system of lines can be drawn upon a globe. These lines, called *parallels* and *meridians*, make possible the location of places on the earth's surface. The complete system or network of parallels and meridians is called the *earth grid.*

The *equator*, zero latitude, is a line that passes around the earth halfway between the poles. It is a Great Circle. A Great Circle is (1) the largest circle that can be drawn on the globe and (2) the shortest distance between two points on the earth's

surface, and (3) its plane always passes through the center of the earth. If a wire hoop is made to fit snugly around the equator, it can be adjusted so as to pass through any two points on the earth's surface, indicating the shortest, or Great Circle, distance between these points. Ocean liners and airplanes follow Great Circle routes whenever possible.

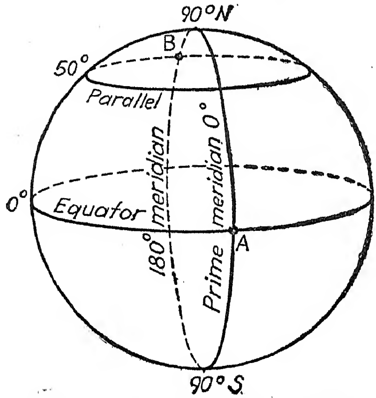

FIG. 8.—In this simplified diagram of the globe are shown one of the parallels and a Great Circle, made up of two meridians. Point *A* on this diagram could be located on any map by the direction "0° Long., 0° Lat."; point *B*, by the direction "180° Long., 50°N. Lat."

A *parallel* is an east-west line, drawn completely around the earth, with all points equidistant from the equator. Parallels are called *Small Circles* because each one is smaller than the equator, the size decreasing as the poles are approached (Fig. 8). The Great Circle distance between two points on the same parallel is shorter than that along the parallel itself (Fig. 9).

Latitude is distance measured in degrees north and south of the equator. From the equator to either pole is 90°. Parallels of latitude on a map or globe may be drawn 1, 5, 10, or any other convenient number of degrees apart. All points on the same parallel have the same latitude. One degree of latitude is always about 69 miles. Philadelphia is on the 40th parallel of north latitude. Its distance from the equator is, therefore, about 2,760 miles. Latitude is determined by a sextant, an instrument that measures the angle between the sun's rays and a tangent to the earth's surface. This angle is called the *sun altitude* (Fig. 10). The altitude of the North Star is made use of in calculating latitude at night. On board ship, latitude is usually determined

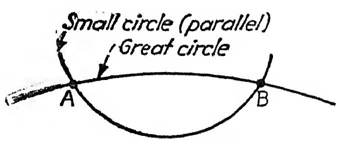

FIG. 9.—The distance between two points on a parallel (a small circle) may be covered more quickly by following a Great Circle route than by following the arc of the parallel. The Great Circle path on a globe may be observed by stretching a string tightly between any two places. The arc of the larger circle more nearly approaches a straight line.

at noon, provided the sun is not hidden by clouds. One degree of latitude (or longitude) is divided into 60 minutes ($'$), and 1 minute into 60 seconds ($''$). Thus the exact latitude of a given point may be 49°56′14″N.

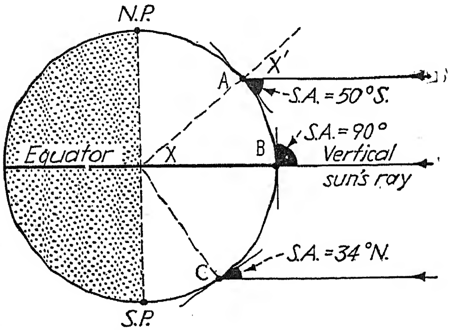

FIG. 10.—Point *B* represents any point on the equator at noon at the time of an equinox. The sun is directly overhead, with its rays striking the equator at an angle of 90°. At Philadelphia (*A*) the angle is 50°S. At Cape Horn (*C*) the angle is 34°N. Since angle $X = X'$ it is evident that the latitude of $A = 90° - S.A.$

Four parallels of latitude are of special importance. Because of the $23\frac{1}{2}°$ inclination of the earth's axis, the vertical rays of the

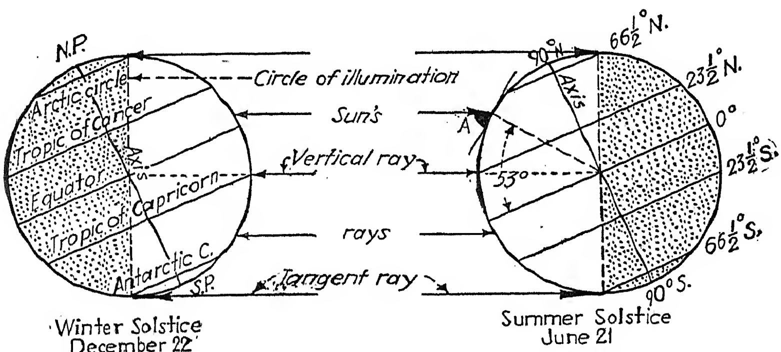

FIG. 11.—These studies of the distribution of light on the earth in winter and summer present in detail two of the positions illustrated in Fig. 4. The sun's rays are shown by parallel lines. Note the shifting of the vertical ray. Angle *A* is the noon sun altitude at a point 53°N. Lat. On the June 21 diagram, what is the sun altitude of the Tropic of Cancer? The Antarctic Circle at noon? The Arctic Circle at midnight?

sun move $23\frac{1}{2}°$ north and south of the equator (Fig. 11). The *Tropic of Cancer* is the parallel $23\frac{1}{2}°$N. and is the farthest north reached by the vertical rays of the sun at the time of the *summer solstice*, about *June* 21 (Northern Hemisphere). The *Tropic of Capricorn* is the parallel $23\frac{1}{2}°$S. and is the farthest south reached

by the vertical rays of the sun at the time of the *winter solstice*, about *December 22*. The *Arctic Circle* is the parallel 66½°N. and is determined by the point where the sun's noon rays are tangent to the earth's surface at the time of winter solstice. The *Antarctic Circle* is the parallel 66½°S. and is determined by the point where the noon sun's rays are tangent to the earth's surface at the time of summer solstice. These four parallels are often considered as the boundary lines between the tropical, intermediate, and polar zones of the earth. The vertical rays of the sun cross the equator twice each year. The time of their first crossing, about

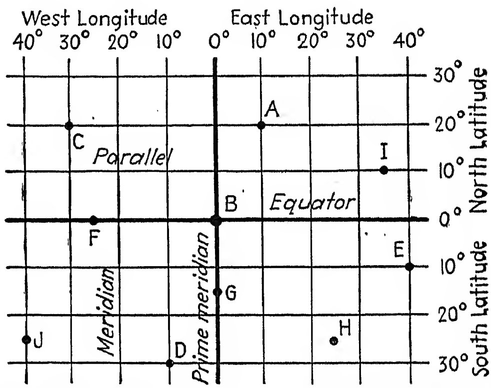

Fig. 12.—Point *A* is 10°E. Long. and 20°N. Lat. Give the longitude and latitude of the other points.

March 21, is called the *vernal equinox*. Their second, about *September 21*, is called the *autumnal equinox*. On these dates, day and night are equal everywhere on the earth, each being 12 hours.

A *meridian* is a north-south line drawn on a globe from pole to pole. Each meridian is one-half a Great Circle. All places on the same meridian have the same longitude. Meridians may be spaced any convenient number of degrees apart on a map or globe. The prime meridian is zero longitude and passes through Greenwich, near London, England.

Longitude is distance measured in degrees east and west of the prime meridian. The only point on the earth's surface having zero longitude and zero latitude is in the Gulf of Guinea on the west coast of Africa where the equator crosses the prime meridian (Fig. 12). Longitude extends 180° east and 180° west from the prime meridian.

Opposite the prime meridian is the *international date line* which roughly follows the 180th meridian near the center of the Pacific Ocean (Fig. 13). This is the line "where day begins and ends." Travelers crossing the date line going west add a day and going east subtract a day. When it is noon on the prime meridian, it is midnight on the 180th meridian. Likewise, when it is noon on the meridian of 90°W. Long. (near St. Louis, Mo.), it is midnight on the meridian of 90°E. Long. (near Calcutta, India).

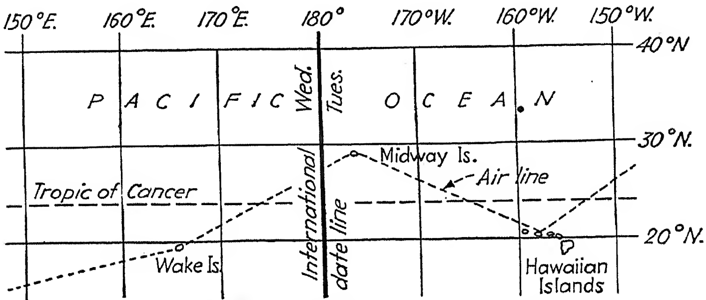

FIG. 13.—When crossing the international date line going west, travelers add a day; going east, they subtract a day. Only when it is midnight on the date line is the whole world living in the same day.

Degrees of Longitude Vary in Length. All the parallels of latitude, except the equator, are smaller than a Great Circle. Since each parallel, regardless of its circumference, is divided into 360°, it follows that the length of 1° of longitude, in miles, must decrease toward the poles. One degree on the equator, a Great Circle, has about the same length as an average degree of latitude (about 69 miles).

The following table gives the approximate mileage per degree of longitude along certain parallels:

Latitude, Degrees	*Miles per Degree of Longitude*	*Latitude, Degrees*	*Miles per Degree of Longitude*
0	69	50	44
10	68	60	34.5
20	65	70	23
30	59	80	12
40	53	90	0

The longitude of an unmapped place east or west of the prime meridian or of a ship at sea can be determined only by finding the *difference in time* between that place and the prime meridian. This was first accomplished by means of accurate timepieces (chronometers) carried on board ship and set at Greenwich, or prime meridian, time. Observation of the sun at the instant when it reached the highest point (zenith) in its daily course across the sky gave local noon time which could then be compared directly with the chronometer, and the difference in time translated into degrees and minutes of longitude (Fig. 14). Now, instantaneous communication by telegraph and radio makes accurate time comparison possible almost everywhere and, therefore, makes possible greatly improved determinations of longitude. This is of particular aid in geographical exploration, aviation, and ocean transportation.

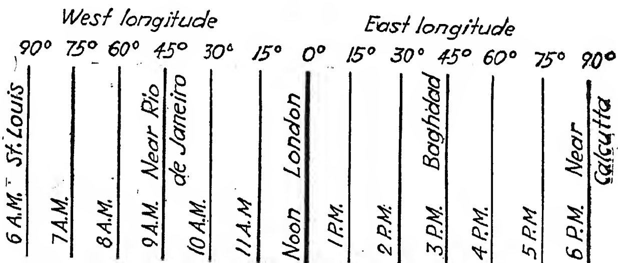

FIG. 14.—Fifteen degrees of longitude equal 1 hour of time. When it is noon in London, it is 6 A.M. in St. Louis, Mo., and 6 P.M. near Calcutta, India. Suppose that on board ship the sun time is noon (sun due south) and London time (by radio) is 3 P.M. The ship is 45°W. Long. What would be the longitude of a ship that at noon received London time as 9 A.M.? 6 A.M.? Midnight?

Accurate Location. The intersection of any two lines is a point. Consequently, any point on the earth's surface may be located by determining that it lies at the intersection of a certain meridian with a certain parallel. By exact determination of its latitude and longitude the location of any place may be expressed briefly and with great accuracy. Thus, when we say that the dome of the national Capitol at Washington, D.C., is located at 38°53′23″N. Lat. and 77°00′33″ Long. west of Greenwich, we have stated its exact position on the earth to within 10 paces.

Longitude and Time. The earth rotates eastward through its entire circumference of 360° of longitude in 24 hours, therefore through 15° in 1 hour. When noon arrives at any meridian, it is already 1 hour later (1 P.M.) on the meridian 15° east of that one, and it lacks 1 hour of noon (11 A.M.) on the meridian 15° to the west. When the sun is directly over a given meridian, it is noon at all points on that meridian from North Pole to South Pole. Four minutes later it is noon on the meridian 1 degree farther west.

In a generation past, each town kept the time of its own meridian which was called *apparent solar time* or, in common American parlance, *sun time*. When rail transportation permitted rapid travel, it became awkward or impossible to change one's time a few minutes with every village passed. To avoid this necessity, each railroad adopted an arbitrary time scheme which differed from that of most of the places it passed through but was the same for considerable distances on the rail line. Unfortunately, several railroads in a region often adopted different times for their own use. Consequently, it sometimes happened that a town reached by different railways found itself required to use or distinguish between several different kinds of time; its own solar time and one for each of its railways.

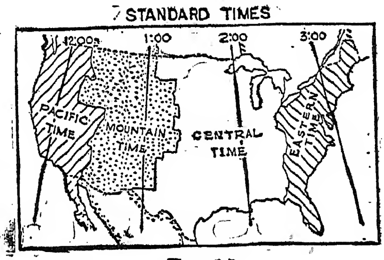

FIG. 15.

The awkwardness and confusion of this situation led to the adoption by American railways, in 1883, of a system of standard time. This system, in theory, supposes that all parts of a north-south zone 15° of longitude in width adopt the solar time of the central meridian of that zone. Places within the zone that are east or west of the central meridian, instead of differing in time by a few minutes from it and from each other, all have the same time. Changes of time are then necessary only in crossing the boundary of the zone, and each change is exactly 1 hour. The timepiece is set forward (as from 12 to 1) in traveling east and is set back (as from 12 to 11) in traveling west. In practice,

these zones are not bounded by meridians but by irregular lines, the location of which is dictated by railway convenience and political consideration. Figure 15 shows the present standard time zones of the United States.

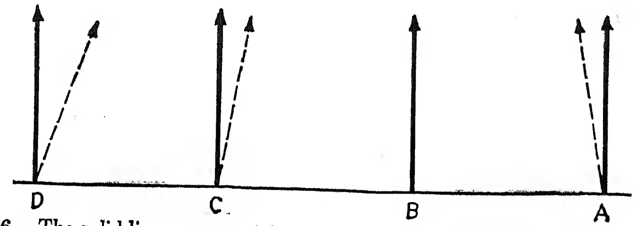

FIG. 16.—The solid lines represent true north as indicated by meridians. The dotted lines show magnetic north as indicated by a magnetic compass. The magnetic variation at *A* (in New York) is 10°W.; at *D* (in Washington), 20°E.; at *C* (in Kansas), 10°E.; and at *B* (western Michigan), zero. At *B*, on the agonic line, the compass points both true and magnetic north.

On the whole earth there should be 24 standard time zones, each extending from pole to pole and each differing from Greenwich time by a definite number of hours. In practice, the arrange-

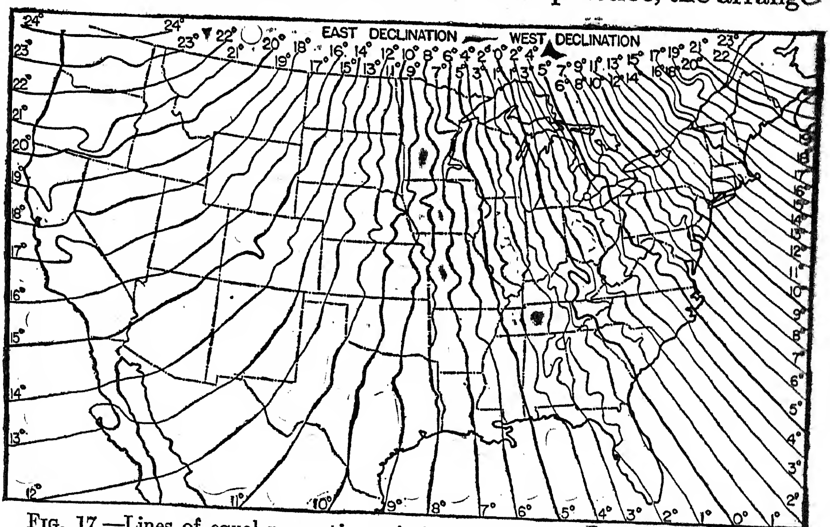

FIG. 17.—Lines of equal magnetic variation or declination (isogonic lines) in the United States. Only at points on the agonic line (0° declination) does the magnetic compass point true north. (*Generalized from a map by U.S. Coast and Geodetic Survey.*)

ment is not quite so simple. Although most countries follow the plan, certain isolated countries employ standard meridians that are not multiples of 15 and, therefore, do not differ from Greenwich time by exact hours. For example, Netherlands time is 19

minutes faster, and Bolivian time is 4 hours and 33 minutes (instead of 5 hours) slower than Greenwich time.

Direction. Places may be located in terms of direction such as northeast (45°), east (90°), southeast (135°).

Much direction finding, especially in land surveys, still is accomplished by means of the magnetic compass. The needle of this instrument aligns itself with the magnetic lines of force that surround the earth. The magnetic north and south poles of the earth happen not to be located at the geographical poles, are not exactly opposite each other, and even are subject to slight changes of position. In consequence, there are few places on the earth where the magnetic needle points true geographical north.

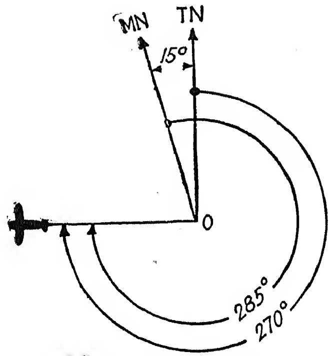

FIG. 18.—The magnetic variation at Boston, Mass., is 15°W. The heading of an airplane from the starting point *O* is west, or 270°. Because of the variation, the compass will read 285° instead of 270°. *TN* is true north (a meridian). *MN* is magnetic north as shown by a magnetic compass. The angle measured clockwise from true north to the heading of the plane (270°) is called the *true course;* from magnetic north to the heading of the plane is the *magnetic course.* What would the magnetic course be if the starting point was in southern California where variation is 15°E.?

The *agonic line* connects those places where the magnetic compass points true north as well as magnetic north. In the United States this line follows a very irregular course from Michigan to South Carolina (Figs. 16, 17). East of the agonic line, as in New York, the magnetic compass points a few degrees west of true north. West of the agonic line, as in Colorado, magnetic north (indicated by the compass) is east of true north (indicated by a meridian). *Magnetic variation,* or *declination,* is the angle between true north and magnetic north (Fig. 16).

An *isogonic line* connects places of *equal* magnetic variation. In flying across country an airplane pilot must be familiar with changes in magnetic variation and know how to calculate true directions from compass readings (Fig. 18). True north is indicated by the shadow of a vertical rod, or plumb line, at noon, sun time; or by the North Star at night. Recent improvements in the radio compass and directional radio-beam navigation

make pilots and navigators less dependent on the magnetic compass than in past years. A good navigator, however, seldom relies entirely on one system of navigation.

Summary

In this chapter we have considered a few facts concerning the earth in space. The size, shape, and motions of the earth greatly influence our daily lives. The system of longitude and latitude (1) helps us in locating places and (2) provides a method of measuring distances on the earth. Longitude is useful in establishing time belts. The earth's magnetism is useful in the navigation of aircraft and ocean liners.

We have learned the meaning of the lithosphere, the hydrosphere, and the atmosphere. The next few chapters deal with the atmosphere and include mainly a study of weather and climate.

Questions

1. What are the members of the solar system?
2. What is a planet? A satellite?
3. In what order do the planets range from the sun?
4. How do planets differ from stars?
5. About how long does it take the moon to revolve once about the earth? What causes an eclipse of the sun? Of the moon?
6. What is the shape of the earth?
7. What is the greatest ocean depth? The height of the highest mountain?
8. The average depth of the oceans is $2\frac{1}{2}$ miles. How much would this be on a globe 4 feet in diameter and having surface features molded to scale?
9. What is the probable reason for the polar flattening of the earth?
10. The polar diameter of the earth is how many miles? The equatorial diameter? What is the difference between these two diameters? How does the earth's diameter compare with that of Jupiter?
11. What are some effects of the force of gravity? What is a vertical line?
12. What is one method of establishing a true north-south line?
13. What is the lithosphere? The hydrosphere? The atmosphere?
14. What percentage of the earth's surface is water? What percentage land?
15. Why is much of the land surface sparsely populated?

16. What are the two principal motions of the earth?

17. What is the earth's axis? The poles? The circle of illumination?

18. What are some results of rotation of the earth on its axis?

19. What is the average distance from earth to sun?

20. The earth makes one revolution around the sun in how many days? (Find out the periods of revolution of the other planets.)

21. What is the earth's orbit? What is the shape of the earth's orbit? What holds the earth in its orbit?

22. What is the difference between gravity and attraction of gravitation?

23. What is a meteor?

24. What is the plane of the orbit?

25. How much is the earth's axis inclined?

26. What is meant by the parallelism of the axis?

27. What are three results of the combined effects of inclination, parallelism, rotation, and revolution?

28. What is the earth grid? The equator?

29. What are three characteristics of a Great Circle?

30. Why do airplanes and steamships follow Great Circle routes?

31. What is a parallel? Latitude? What is the latitude of the equator? The poles? Why are parallels called *Small Circles*?

32. Why is the Small Circle distance between two points greater than the Great Circle distance?

33. One degree of latitude is about how many miles? What is the latitude of New Orleans? How many miles is it from the equator?

34. What is meant by sun altitude? With what instrument is it measured?

35. In what two ways may latitude be calculated?

36. What is the Tropic of Cancer? The Tropic of Capricorn? The Arctic Circle? The Antarctic Circle?

37. What is the summer solstice? Winter solstice? Vernal equinox? Autumnal equinox?

38. What is a meridian? The prime meridian? Longitude?

39. What point has zero latitude and zero longitude?

40. Where is the international date line? What is the purpose of this line?

41. When it is noon 60°E., at what longitude is it midnight?

42. What is the length in miles of 1° of longitude on the equator? On the 30th parallel? On the 80th parallel?

43. By what method is longitude determined?

44. How is the exact location of a point on the earth's surface expressed?

45. What are the longitude and latitude of New York, London, Peiping, Cape Town, Buenos Aires, Melbourne, Honolulu, and Manila? (Use maps.)

46. How many degrees of longitude equal 1 hour of time?

47. Why was the system of standard time adopted?

48. What determines the standard time of any belt?

49. What are the standard time belts of the United States? When it is 11.00 P.M. in Denver, what is the time in Los Angeles? New York? Chicago?

50. The prime meridian, 0, determines the standard time of London and Paris. When it is noon in St. Louis, Mo., what time is it in London?

51. Where, by longitude and latitude, are the earth's magnetic poles? (Use maps.)

52. Why does a magnetic compass not point true north at most places?

53. What is the agonic line? Magnetic variation? Isogonic line?

54. What is the magnetic variation in your locality? (Magnetic variation is usually shown on topographic maps and always on airway maps.) What is the variation at Pittsburgh? Muskegon, Mich.? St. Louis? San Francisco?

55. In what two ways can you determine true north?

Suggested Activities

1. Construct a homemade sextant. Keep a daily record of the sun altitude at noon for several months. At the time of equinox, the sun altitude substracted from 90° will give your latitude.

2. On a clear night, locate the North Star by means of the Big Dipper. The direction of the North Star is true north.

3. Erect a vertical rod or plumb line, and mark the positions of its shadow at various hours of the day.

4. Practice pointing in the direction of large cities.

5. Observe and record the direction of sunrise and sunset on the twenty-first of June, September, December, and March. Record the sun altitude at noon on these dates and the number of hours of sunlight. Suppose you lived on the Strait of Magellan. How would these observations differ from those made in your own locality?

6. Some people are lost when they enter strange cities. To avoid this, practice reading the maps of cities that you expect to visit. Learn directions from place to place. Maps of cities are found in connection with automobile highway maps. Place your map so that north on the map is really in the direction of north.

7. Make a list of 25 large cities scattered over the various continents. By using maps, determine as closely as possible the longitude and latitude of each.

8. If possible, visit an airport. Observe the magnetic compass, radio compass, and directional radio-beam apparatus.

9. Find out the magnetic variation in your local community.

NOTE: Other activities may be found in the laboratory manual.

TOPICS FOR CLASS REPORTS

1. The Solar System
2. Proofs that the Earth Is Spherical in Shape
3. The Royal Astronomical Observatory at Greenwich
4. The Locations of Great Circle Routes between Important Cities
5. Standard Time Belts of Europe
6. The International Date Line
7. The Earth as a Huge Magnet
8. Magnetic Variation in Different Parts of North America

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Chapter II. Temperature of the Atmosphere

Man lives on the solid portion of the earth's surface but in, and at the bottom of, a sea of air which is many times deeper than any ocean. This sea of air, or the atmosphere, has certain characteristics that greatly influence man's life. Of the various elements of natural environment that affect the usefulness of the earth's regions for human beings, such as climate, landforms, minerals, soils, and native vegetation, climate probably is the most important single item. This is because climate affects a region's usefulness not only directly but also indirectly through its influence upon native vegetation, soils, and landforms. Thus large areas with similar climates are likely to have strong resemblances also in vegetation and soils.

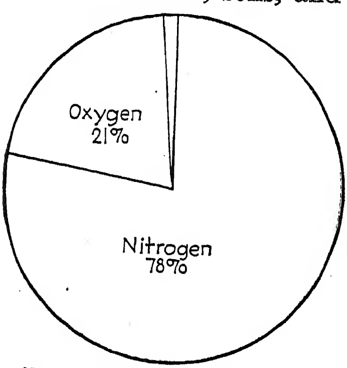

FIG. 19.—The atmosphere is composed mainly of nitrogen and oxygen. Both are colorless, odorless gases.

Pure, dry air near sea level is a mechanical mixture of a number of gases. Two of them, nitrogen (78 per cent) and oxygen (nearly 21 per cent), together comprise 99 per cent of the total by volume (Fig. 19). At higher elevations, certain lighter gases, especially hydrogen, predominate. In the atmosphere also are smaller amounts of carbon dioxide, argon, ozone, and others. In addition to these gases the lower layers of air contain variable amounts of water vapor (up to nearly 5 per cent on hot, humid days) and numerous impurities classed as dust.

As far as climate and weather are concerned, certain of the minor gases of the air are far more important than nitrogen and

oxygen. Subtract the single item, water vapor, from the air, and rainfall would cease. This invisible vapor condenses to form clouds, fog, dew, frost, rain, snow, sleet, and hail. Water vapor acts as a sort of blanket in helping to regulate the temperature of the air, because it readily permits sun energy to reach the earth but tends to retard the radiation of heat from the earth.

Certain kinds of dust particles serve as nucleuses upon which water vapor condenses to form raindrops. Dust in the air is largely responsible for the colors of sunrise and sunset, the blue of the sky, and the occurrence of twilight and dawn. Abundant smoke and dust over large cities act as a screen to incoming sunlight and greatly hinder visibility. A combination of smoke and fog is known as *smog* and at times, especially near cities, is a severe hindrance to aviation.

Elements of Weather and Climate. The principal elements of the atmosphere that largely determine the weather or climate at any given time or place are temperature and precipitation (including humidity and clouds). In addition to these are such elements as atmospheric pressure, winds, storms, and visibility. Weather is the sum total of these elements for a short period of time. Two friends meet on the street and speak of the weather for today or of last week. Climate is the generalization of the great variety of weather conditions over a long period of time.

The Controls of Weather and Climate. Variations in weather and climate are due to the climatic controls, which are (1) latitude, which largely determines (*a*) the angle of the sun's rays and thus their effectiveness and (*b*) the duration of sunlight; (2) distribution of land and water; (3) winds; (4) elevation; (5) mountain barriers; (6) the great semipermanent high- and low-pressure centers; (7) ocean currents; and (8) storms of various kinds. These controls, acting with various intensities and in different combinations, produce changes in temperature, which in turn give rise to varieties of weather and climate. It is well to remember that climatic controls acting upon climatic elements produce various types of weather and climate.

Temperature

Sources of Atmospheric Heat. The sun is the most important source of heat for the earth's atmosphere. Out into space

from this gigantic body, whose diameter is more than one hundred times that of the earth and whose surface temperature is estimated to be more than 10,000°F., streams a tremendous amount of energy. The earth, nearly 93 million miles distant, intercepts only a tiny part of this output. The radiant energy received from the sun, transmitted in the form of short waves and traveling at the rate of 186,000 miles per second, is called *solar radiation*, or *insolation*. To the small amount of insolation received at the earth's surface most of the physical and all the biological phenomena of the earth owe their existence. The distribution of insolation over the earth's surface is of outstanding significance in understanding weather and climate. Certainly the sun, or insolation, is the greatest single control of climate.

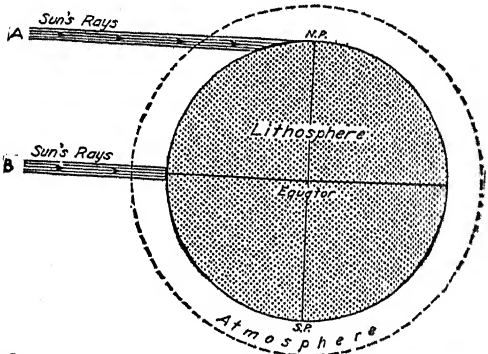

FIG. 20.—Rays that are slanting (*A*) as they reach the earth deliver less energy at the earth's surface than vertical rays (*B*), for two reasons: They must pass through a thicker layer of atmosphere, and they spread their energy over a wider area.

Effectiveness of Insolation. The amount of insolation received at any given place depends mainly upon (1) the length of day (number of hours of sunlight) and (2) sun altitude, or the angle at which the sun's rays strike the earth. For two reasons oblique solar rays deliver less energy to the earth's surface than direct rays: (1) Oblique rays are spread over a larger area than are direct rays; (2) oblique rays pass through much more air than direct rays, and the air tends to absorb, scatter, and reflect some of the solar energy (Fig. 20). Winter sunlight, therefore, is much weaker than that of summer. At Kansas City, Mo., 39° N.Lat., for example, the noon sun altitude around December 21 is about 28°; in the latter part of June it is about 74°. Added

to this great difference in the angle of the sun's rays is the fact that there are many more hours of sunlight in June than in December.

LENGTH OF THE LONGEST DAY (ALSO OF THE LONGEST NIGHT IN THE OPPOSITE HEMISPHERE) AT CERTAIN LATITUDES

Latitude	Equator	17°	41°	49°	63°	66½°	67°21′	69°51′	78°11′	90°
Duration (hr.)	12	13	15	16	20	24	1 mo.	2 mo.	4 mo.	6 mo.

The earth is some 3 million miles closer to the sun in January than in July. That there is a cold season in the Northern Hemisphere at the time when the earth is nearest the sun and a warm season when it is farthest from the sun tends to emphasize the fact that this item of distance is minor compared with length of day and the angle of the sun's rays. In general, it is well to remember that the higher the sun altitude and the longer the days the higher the temperature; and the lower the sun altitude and the shorter the days the lower the temperature.

Much sun energy that reaches the earth's outer atmosphere is prevented from heating the earth's surface. A considerable percentage is lost by reflection from clouds, small dust particles, molecules of air, and the earth's surface. Some 10 to 15 per cent is absorbed directly by the atmosphere. About 50 per cent reaches the earth's surface, heats it, and eventually heats the atmosphere as well.

Seasons. An explanation of the change of seasons as regards temperature is given in Appendix A and should be studied carefully at this point. The inclination and parallelism of the earth's axis are responsible for the day-to-day change in sun altitude and length of day resulting in the change of seasons. One should constantly bear in mind that the *time* of seasons in the north and south intermediate zones is reversed. When it is summer in the United States, it is winter in Argentina. The change of seasons in the intermediate zones is much more pronounced in the interiors of large continents than along windward coasts where ocean influence is felt.

Heating and Cooling of Land and Water Surfaces

Land and Water Contrasts. Sun energy is of such a nature that only relatively small amounts (10 to 15 per cent) of it can be absorbed by the earth's atmosphere. In order to be absorbed by

the air, it must first be converted into heat energy given off by the earth. This conversion takes place principally at the earth's surface. Thus the atmosphere receives most of its heat directly from the earth's surface and only indirectly from the sun.

For the following reasons land surfaces heat and cool more rapidly than water surfaces:

1. Much more heat is required to raise the temperature of 1 cubic foot of water 1° than is required for 1 cubic foot of soil or rock.[1]

2. The sun's rays penetrate to considerable depths in water and are thus required to heat a greater mass than is the case with land. Since land is opaque, only the surface layers of soil and rock are heated to any extent.

3. Water, being a fluid, has movements in the form of waves, drifts, currents, and tides that tend to distribute the absorbed solar energy throughout the whole mass. Obviously, no such distribution and mixing can take place in landmasses, and the land surface, therefore, attains a higher temperature. Moreover, when a water surface begins to cool, convectional currents are set up, the cooler, heavier surface layers sinking and being replaced by warmer waters from underneath. Therefore, water bodies cool much more slowly than do land bodies and tend to act as regulators of air temperature.

From the foregoing comparisons it becomes evident that, with the same amount of solar energy falling upon each, a land surface will reach a higher temperature, and reach it more quickly, than a water surface. Conversely, a land surface also cools more rapidly. Land-controlled, or *continental*, climates, therefore, should be characterized by large daily and seasonal extremes of temperature; on the other hand, ocean-controlled, or *marine*, climates should be more moderate.

How the Atmosphere Is Warmed

We are now acquainted, as a result of our earlier discussion, with the distribution of solar energy over the earth and the

[1] *Specific heat* is the term applied to the amount of heat (calories) required to raise the temperature of 1 gram of a substance 1°C.

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contrasting reactions of land and water surfaces to this solar energy. We are also aware that the air receives most of its energy directly from the surface upon which it rests and only indirectly from the sun. This is sufficient background for an analysis of the processes involved in heating and cooling the atmosphere.

Absorption of Sun Energy. As previously stated, the atmosphere absorbs directly only about 10 to 15 per cent of the solar energy that comes to it. Such absorption takes place mainly in the upper layers of the air. This process, therefore, is not very effective in heating the layers of air close to the earth. Often on a clear winter day, when snow covers the ground, air temperatures may remain bitterly cold in spite of a bright sun. At the same time, on the south side of a brick building, the temperature may be much more comfortable. This is because the brick wall absorbs sun energy and converts it into a form of heat energy that is effective in warming the surrounding air.

Conduction from the Warm Earth. *Conduction* refers to the transfer of heat (1) through a substance, such as a metal rod, and (2) from a warm substance to a cooler one, provided they are in contact. During the daylight hours the solid earth (without a snow cover) absorbs much solar energy and becomes warmer than the surrounding atmosphere. By conduction, therefore, the layer of air resting upon the warmer earth becomes heated. Air, however, is a poor conductor. As a result, the transfer of heat from the lower, warmed layers of air to those above is very slow. It is a well-known fact that, ordinarily, as one goes up in the air the temperature drops.

The Air Absorbs Heat Radiated from the Earth. Since the earth absorbs solar energy, it becomes warm and therefore radiates heat just as the sun does. This heat radiated from the earth is readily absorbed by the air. It is estimated that, although only 10 to 15 per cent of the solar energy is absorbed by the atmosphere, some 90 per cent of the radiated earth energy is absorbed. As stated before, water vapor and, to a lesser extent, carbon dioxide and ozone are the principal absorbing gases. One reason for the rapid night cooling in deserts is that the dry air and clear sky permit a more rapid escape of the heat that is radiated from the earth. One may think of the atmosphere as being somewhat like a pane of glass which lets through most of the incoming

solar energy but greatly retards the outgoing heat, or earth radiation. This is the so-called *greenhouse effect* of the atmosphere.

Through the first three heating processes described above, there is actually an addition of energy to the atmosphere. Through the three processes whose description follows, there is no addition of energy but only a transfer from one place to another, or from one air mass to another, of that which already has been acquired.

Convectional Currents from the Warm Earth. The surface air after being heated by conduction and radiation expands in volume and consequently decreases in density.[1] Because of expansion, a portion of the warmer, lighter column of air overflows aloft, thereby decreasing its own pressure at the surface and at the same time increasing that of the adjacent cooler air. This causes a lifting of the warmer, lighter air column by the heavier, cooler, settling air which flows in at the surface to displace it. Such a circulation as described above and illustrated in Fig. 21 is called a *convectional system.* Warm surface air, expanded and therefore less dense, is like a cork that is held under water, *i.e.*, it is unstable and inclined to rise. This convectional principle (which applies to liquids and gases only) is employed in the ordinary hot-air and hot-water heating systems. On a hot summer day "bumpy" air is experienced when an airplane alternately crosses rising and sinking air currents.

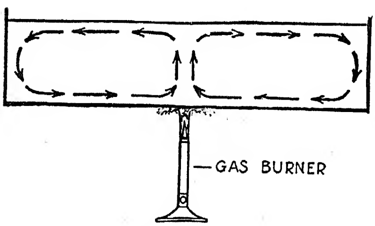

Fig. 21.—Representation of a convectional circulation.

Conduction and radiation are especially effective in heating the lower layers of atmosphere, but convection, on the other hand, is capable of carrying heat to the upper air strata as well.

Importation by Air Masses or Winds. "It will be warmer today because there is a south wind." Such a remark is common in many parts of North America and Europe. The south wind may be an air mass of tropical origin which is advancing northward. In so doing, it conveys the temperature conditions acquired in its source region where high temperatures are normal.

[1] Density means weight per unit volume.

Such an importation of southerly warmth in winter results in mild weather, with melting snow and sloppy streets. In summer several days of south wind may result in a "hot wave" with maximum temperatures of 90° to 100° or above.

Heating by Compression. A mass of air generally becomes warmer as it descends from higher to lower altitudes, *e.g.*, when it moves down a mountain slope. At lower altitudes, a thicker layer of air is pressing down upon the descending air mass, which gradually is being compressed in volume. Work is being done upon the descending air, and as a result of compression its temperature is increased.

How the Atmosphere Is Cooled

Radiation to the Cooler Ground and to Space. During the night the earth's surface may radiate heat so rapidly that it becomes cooler than the air above it. When this condition prevails, the lower layers of atmosphere lose heat by radiation to the colder ground as well as upward toward space. This process is particularly effective during the long nights of winter when, if the skies are clear and the air is dry and calm, very rapid and long-continued radiation takes place. If snow covers the ground, cooling is even more pronounced. This causes a greater decrease in the temperature of the lower layers of air.

Water, like land, is a good radiator, but the cooled surface waters keep constantly sinking to be replaced by warmer currents from below. Extremely low air temperatures over large water bodies are impossible, therefore, until they are frozen over, after which they act like a snow-covered land surface. Humid air or a cloudy sky tends to prevent rapid earth radiation, so that air temperatures remain higher. Thus frosts are less likely to occur on humid nights and especially when a cloud cover prevails. There are authentic cases in the dry air and under the cloudless skies of the Sahara Desert in northern Africa, where day temperatures of 90° have been followed by night temperatures slightly below freezing.

Conduction to the Cold Earth. As previously stated, conduction is the transfer of heat between two substances that are in contact. As the earth's surface cools during the night, conduction of heat from air to earth causes a lowering of air temper-

ature. Often on a calm, clear winter or summer night, the layers of air close to the earth actually become colder than those at some distance above the earth's surface.

Importation by Air Masses or Winds. Just as warm air masses carry warmth northward (south wind in the Northern Hemisphere), so likewise do cold air masses convey low temperatures from one place to another. Especially in North America and Eurasia, cold polar air masses from the far north may move southward for considerable distances. Such movement (north wind) and resulting importation of low temperatures are particularly effective where there are no mountain barriers to block the passage of air. In eastern North America where lowlands prevail, great masses of cold polar air periodically pour down over the Mississippi Valley, occasionally carrying severe frosts even to the Gulf states.

Cooling by Expansion. Just as descending air heats as a result of compression, so rising air cools as a result of expansion. A cubic foot of air at low altitudes is subject to greater atmospheric pressure than at high altitudes. As this cubic foot of air rises, it expands because the weight of the atmosphere upon it becomes less. Work is done in pushing aside other air in order to make room for itself. This work done by the rising and expanding air consumes energy, which is subtracted from the ascending currents in the form of heat, resulting in a lowering of their temperature. On the average, rising air cools about 5°F. for each 1,000 feet.

Daily and Seasonal March of Temperature

All average temperatures for a month, season, year, or even a long period of years are built upon the mean (average) daily temperature as the basic unit. The daily mean is thus the individual brick out of which the general temperature structure is composed. The U.S. Weather Bureau at present uses the following formula to determine the mean daily temperature:

$$\frac{\text{Maximum} + \text{minimum}}{2}$$

In other words, the daily mean is the average of the highest and the lowest temperatures recorded during the 24-hour period.

Daily Temperatures. The daily march of temperature refers to the hourly changes in the thermometer readings during the day (24 hours). From about sunrise until 2 to 4 P.M., when energy is being supplied by incoming solar radiation faster than it is being lost by earth radiation, the temperature curve usually continues to rise. Conversely, from about 3 P.M. to sunrise, when loss by earth radiation exceeds receipts of solar energy, the daily temperature curve usually falls. It is noticeable, however, that the time of highest temperatures (2 to 4 P.M.) does not exactly coincide with that of maximum insolation (12 M. sun time).

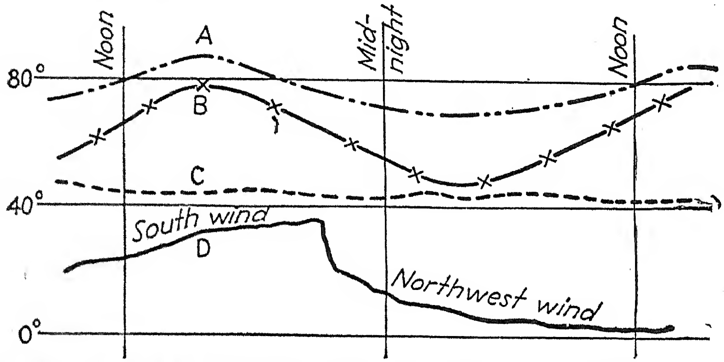

FIG. 22.—Temperature sometimes varies many degrees in a single day. In the chart above, *A* shows the temperature range for a fair day in summer; *B*, for a summer day in the mountains. Contrast these with *C*, a cloudy day in spring or fall, and *D*, a winter day on which the wind changed from south to northwest.

This is because incoming solar radiation continues to exceed outgoing earth radiation until midafternoon. The lowest temperatures of the night usually occur about 4 to 6 A.M. because the earth continues to radiate more heat than it receives until near sunup.

The *daily range of temperature* is the difference between the highest and lowest temperatures of the day. In clear weather, throughout most of central and eastern United States, this range is about 10° or 15°. In mountains it is much greater, because the less dense atmosphere at high elevations permits more rapid radiation of heat from the earth at night, and consequently lower temperatures result. Daily range is usually greater in deserts than in humid lands, because the low percentage of water vapor in the air over deserts and the general absence of a cloud cover permit rapid radiation of heat from the earth at night.

During a spell of cloudy weather the daily range may be as little as 5° or less. A cloud cover regulates air temperature, because clouds serve to obstruct incoming and outgoing radiation. However, in clear or cloudy weather, the daily march of temperature may be entirely upset by a shift in wind direction. Thus a strong northwest wind may cause a steady drop in temperature during the day so that midafternoon may be colder than early morning (Fig. 22).

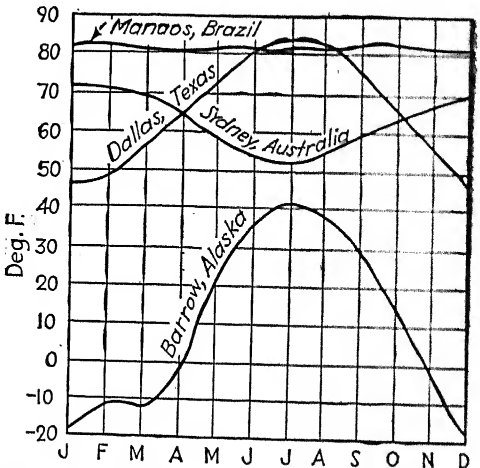

FIG. 23.—The seasonal range of temperature. Note that the coolest month at Sydney, Australia, is July.

The Seasonal March of Temperature. Using the mean daily temperatures, the average or mean temperature of a month may be calculated. This in turn may be used to compute the mean annual temperature. Mean monthly temperatures make it possible to obtain some idea of seasonal changes in temperature in different parts of the world. It is well to remember, however, that in some localities the mean monthly temperature may cover a considerable range. For example, although the mean January temperature at Kansas City, Mo., is 28°, the temperature may actually range from 10° below zero to 45° above during the month. Such extreme changes, however, do not occur on windward coasts (where wind generally blows from sea to land). In the middle latitudes of the Northern Hemisphere, July is usually the warmest month, and January the coldest. Conditions are

reversed in similar latitudes of the Southern Hemisphere (Fig. 23).

Vertical Distribution of Temperature

Temperature Decreases with Altitude. By means of airplanes and balloons, men have soared to considerable heights in the atmosphere. They have recorded temperature readings during such flights. Self-recording instruments, carried aloft by smaller balloons, have reached greater heights. All such observations and recordings show that under normal conditions there is a decrease in temperature as altitude increases. The amount of decrease, of course, varies somewhat from place to place and at different times of the year. On the average, however, the decrease in temperature as altitude *increases*, called the *lapse rate*, is about 3°F. per 1,000 feet. The fact that air temperature decreases as distance from the earth increases emphasizes the fact that the atmosphere receives most of its heat directly from the earth and only indirectly from the sun.

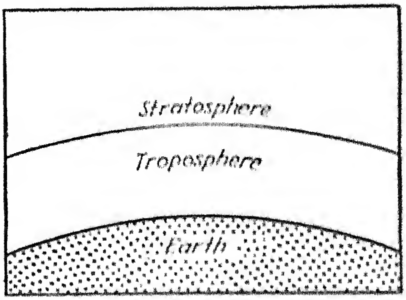

FIG. 24.—The atmosphere is composed of two principal layers, the troposphere and the stratosphere. The elevation of the lower side of the stratosphere in the United States is approximately 7 miles. It is higher at the equator and lower at the poles.

Stratosphere and Troposphere. The average lapse rate of 3°F. per 1,000 feet continues until an elevation of about 7 miles (about 37,000 feet) is reached. From this elevation upward for several miles there is little change in temperature, and to this region the name *stratosphere* has been applied. In it temperatures have been found to be in the neighborhood of −60° to −70°F., although above the equator −110°F. has been recorded. Thus it is possible to think of the earth's atmosphere as composed of two shells or layers. In the outer layer, or stratosphere, temperatures are very low, clouds are absent, dust and water vapor are at a minimum, convectional currents are lacking, and all air movement is horizontal. Below the stratosphere is the turbulent, dusty layer known as the *troposphere*, which contains much water vapor and also clouds, and in which temperature de-

creases with increasing altitude (Fig. 24). For reasons already mentioned, the stratosphere or substratosphere offers certain advantages for long-distance airplane flights.

Air Drainage. Cold air is heavier than warm air. As a result, cold air next to the earth's surface, because of its greater weight, tends to flow downhill and to collect in valleys and lowlands. This is called *air drainage* (Fig. 25). It is a well-known fact that the first frosts of autumn and the last in spring occur in bottom lands and that the lowest temperatures on calm, clear winter nights are found in similar locations. Citrus orchards in California, which might be damaged by frost, are located on hill slopes where air drainage causes a slipping off of the frosty air. Coffee in Brazil is prevailingly planted on the rolling uplands, and the frosty valleys are avoided. Resort hotels in the Swiss Alps shun the cold, foggy valleys and choose instead sites on the brighter and warmer slopes.

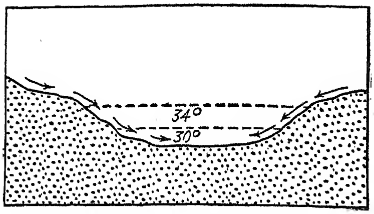

FIG. 25.—Cold air tends to settle at the bottom of a valley or depression. This diagram shows why frost may occur in the valley bottom but not on the hillside.

On clear, cold nights when air drainage is prevalent, the atmosphere is very stable. The heaviest air is at the lowest elevation where, on the basis of density, it should be. There is no inclination for it to rise. This is quite opposite to the unstable condition of the atmosphere on a hot summer day, when the heated and expanded air near the earth's surface is like a cork held under water.

Conditions Favorable for Frost. The term *frost* may be applied either (1) to the white deposits of condensed water vapor in solid form or (2) to a temperature of 32°F. or below, even though there is no deposit of white frost. There are frosts of various degrees of severity, but it is the "killing frost" that is of principal interest. A killing frost may be defined as a temperature condition so low that the economic crops of a locality are damaged. Throughout much of North America, frosts are of chief significance in autumn and spring. The *growing season* is the number of frost-free days between the last killing frost in spring and the first in autumn (Fig. 26). The length of the growing

season has a considerable influence upon the types of economic crops that may be produced in any given region.

Ideal conditions for the occurrence of frost are those which are favorable to rapid and prolonged surface cooling, *viz.*, (1) a preliminary importation of a mass of chilly polar air, (2) followed by clear, dry, calm nights, during which the temperature of the surface air, because of radiation and conduction, may be reduced below freezing. The original importation provides the necessary mass of cool air whose temperature is already rela-

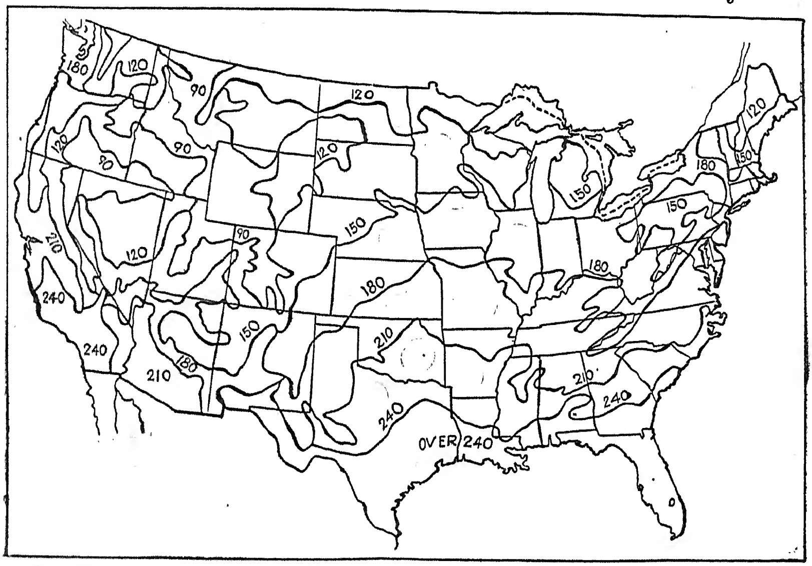

FIG. 26.—The average "frostless," or "growing," season throughout the United States is shown on this map. Figures indicate number of frost-free days. (*After map by U.S. Weather Bureau.*)

tively low, although still somewhat above freezing, but further rapid loss of heat by earth radiation during the following clear night is all that is necessary to reduce the temperature of the surface air below freezing. In central and eastern United States the dry, cold air mass usually arrives with northwest winds. If the daytime temperature of the cold air mass is in the neighborhood of 40°, frost may be expected the following night, especially if the sky is clear and the air calm.

Frost Protection. The problem of artificial protection from frost is of considerable importance, especially in the valuable citrus groves of California and Florida. In these regions, orchard

heaters are used in an attempt to prevent a bad freeze (Fig. 27). Large numbers of such heaters are spaced among the fruit trees and are kept burning for several hours during the time when freezing temperatures are expected. Sometimes the smoke from numerous heaters drifts into a near-by city where it may prove a considerable nuisance.

FIG. 27.—Orchard heaters are placed at regular intervals between rows of orange trees in a citrus grove when fruit is endangered by frost. These shown are of the oil-burning variety, most common in California groves. Coke heaters also are used. (*Courtesy of California Fruit Growers Exchange.*)

For small-scale vegetable gardeners or fruit growers, the simplest and most effective means of frost protection is to spread over the crop a nonmetallic covering such as paper, straw, or cloth. Such a covering tends to intercept the heat that is radiated from the ground and plants at night. The purpose of the cover, obviously, is not to keep the cold out but to keep the heat in. This inexpensive type of frost protection is the one resorted to by the housewife in saving her garden plants from freezing.

Temperature Distribution over the Earth

Isothermal Maps. An *isotherm* is a line connecting places of the same temperature. Thus all points of the earth's surface

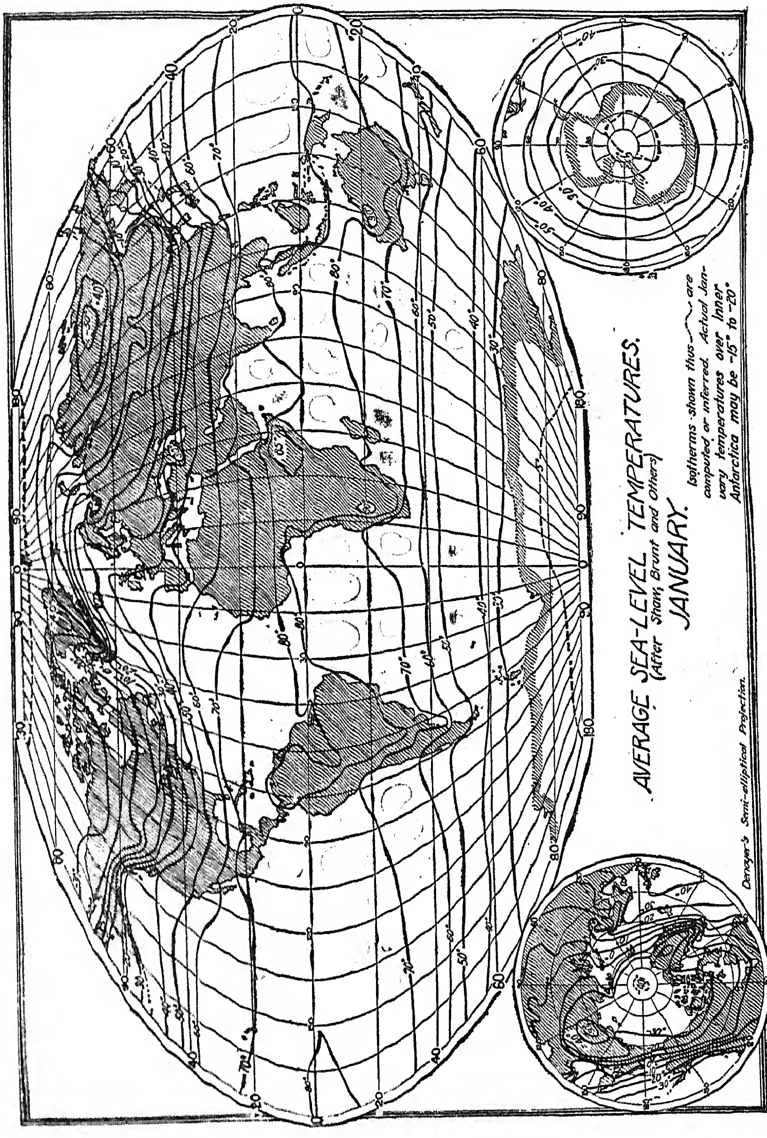
AVERAGE SEA-LEVEL TEMPERATURES.
(After Shaw, Brunt and Others)
JANUARY.
Isotherms shown thus —— are computed or inferred. Actual January temperatures over Inner Antarctica may be -15° to -20°
Denoyer's Semi-elliptical Projection.

Fig. 28.


AVERAGE - SEA-LEVEL TEMPERATURES
(After Shaw, Brunt and Others)
JULY

Fig. 23.

through which any one isotherm passes have identical average temperatures (Figs. 28, 29). On the maps here shown, all temperatures have been reduced to sea level so that the effects of altitude are eliminated. If this were not done, the complications and details caused by mountains and other lesser relief forms would make the maps so confusing that the general world-wide effects of latitude and land-and-water distribution would be difficult to perceive. It will be noted that the isotherms in general trend east and west, roughly following the parallels. This east-west trend indicates that latitude is the greatest single cause of temperature differences over the earth's surface.

General Features of Temperature Distribution. A study of the isothermal maps of the world reveals the following general features:

1. The highest average annual temperatures are in the low latitudes, where the largest amounts of insolation are received. The average lowest temperatures are in the vicinity of the poles, the regions of least annual insolation.

2. Isotherms tend to be straighter and are also more widely spaced in the Southern Hemisphere, where the surface is largely composed of water.

3. The greatest departures from east-west courses are in localities where isotherms pass from continents to oceans or vice versa. That is caused by the contrasting heating and cooling properties of land and water surfaces and the effects of ocean currents. The distribution of land and water bodies ranks next to latitude in the control of temperature distribution. Cold ocean currents off the coasts of Peru and northern Chile, southern California, and southwestern Africa make themselves conspicuous through the equatorward bending of the isotherms. Similarly, warm currents in higher latitudes cause isotherms to bend poleward. This condition is most marked off the coast of northwestern Europe owing to the effects of the Gulf Stream.

January and July Temperatures. For the earth in general, January and July represent the seasonal extremes of temperature. The following are some of the more significant features of temperature distribution as shown on the seasonal maps: (1) The isotherms and temperature belts move north and south, following the north-south migration of the sun's more vertical

rays. (2) The north-south shifting is greater over continents than over oceans, because of greater extremes of temperature over landmasses. (3) The highest temperatures on both the January and the July maps are over land areas. The lowest temperatures in January are over Asia and North America, the largest of the landmasses in middle latitudes. (4) In January in the Northern Hemisphere isotherms bend toward the equator over the colder continents and toward the poles over warmer oceans. In July the opposite conditions prevail. (5) Temperature differences between land and water are less pronounced in the Southern Hemisphere because of the absence of great landmasses. (6) The so-called *cold pole* of the earth is in Siberia, where temperatures of 90° below zero have been recorded.

The *annual range of temperature* is defined as the difference between the average temperatures of the warmest and coldest months. The approximate annual range at any given place can be learned from study of the isothermal maps. Notice, for example, Duluth, Minn. On the July map the nearest isotherm is 70°; on the January map it is zero, an annual range of about 70°. The greatest annual ranges are over the Northern Hemisphere continents, which alternately become hot in summer and cold in winter. Low annual range is observed (1) near the equator, where insolation varies little, and (2) over large bodies of water, which change temperature much more slowly than land areas. The predominance of water in the Southern Hemisphere results in much smaller annual ranges of temperature than in the Northern Hemisphere. Thus the change of seasons at any given place, as regards temperature, is clearly shown by these two maps.

Air Temperature and Sensible Temperature. Correct air temperature can be obtained only by an accurate thermometer properly exposed. One of the principal items of correct exposure is to see that the instrument is not in the sun; otherwise it receives energy not only from the surrounding air but from the absorption of insolation as well. It also should be protected from direct radiation from the ground and adjacent buildings.

Sensible temperature refers to the sensation of temperature which the human body *feels*, as distinguished from actual air temperature which is recorded by a properly exposed thermom-

eter. The human body is a heat engine, generating energy at a relatively fixed rate when at rest. Anything, therefore, that affects the rate of loss of heat from the body affects physical comfort. Air temperature, of course, is an important element, but so also are wind, humidity, and sunlight. Thus a humid, hot day is more uncomfortable than one of dry heat with the same temperature, since the loss of heat by evaporation is retarded more when the air is humid. A windy, cold day feels uncomfortable because the loss of heat is speeded up by greater evaporation. A sunny day in winter feels less cold than it actually may be, because of the body's absorption of direct insolation. Cold air containing moisture particles feels colder than dry cold air. This is because cold-water particles collect on the skin. By conduction, heat is transferred from the skin to the tiny water droplets. Evaporation of the water particles also contributes to a lowering of temperature. Because of its sensitiveness to factors other than air temperature, the human body is not a very accurate thermometer.

Summary

The atmosphere is warmed mainly by the earth, which absorbs sun energy. If the earth's surface is warm, the air above it is likely to be warm. A land surface heats and cools more rapidly than water. Convection currents carry warm air up and cool air down. Rising air cools about 5°F. per 1,000 feet. Roughly, the atmosphere may be divided into two layers called the troposphere and the stratosphere. A thermometer carried upward through the troposphere will show a drop of about 3° per 1,000 feet. This is called the lapse rate. Note that rising dry air, because of expansion, cools faster than the normal drop in temperature with elevation. In the stratosphere temperature is fairly constant. Seasonal changes in temperature are much greater in middle and high latitudes than in the vicinity of the equator.

Cold air is heavier than warm air. As air changes temperature, it also changes weight or pressure. Differences in atmospheric pressure over the earth's surface cause the air to move. Our next chapter, therefore, deals with the subject of atmospheric pressure and winds.

Questions

1. What are several elements of environment? Why is climate a most important one?
2. Name the principal constituents of the atmosphere.
3. Why is water vapor in the air so important?
4. How does water vapor influence air temperature?
5. What are a few effects of dust in the air?
6. What is smog? Where is it most likely to occur?
7. What are the weather elements? Which two are most important?
8. What is meant by weather? Climate?
9. What are the climatic controls?
10. What is the most important source of heat for the earth's atmosphere?
11. What is meant by insolation? Sun altitude?
12. What two factors determine the effectiveness of insolation?
13. Why are oblique sun's rays less effective than direct rays?
14. Winter occurs in the United States when the earth is nearest the sun. Why?
15. In general, what is the relation of sun altitude and length of day to temperature?
16. Approximately, what is the length of the longest day (duration of sunlight) at Singapore? Winnipeg? Point Barrow, Alaska? The North Pole?
17. Why does the atmosphere receive most of its heat indirectly from the sun?
18. How do land and water surfaces differ with regard to absorption of solar energy?
19. The sun's rays penetrate water. How does this influence the rate of heating of a water body?
20. What is the effect of reflection and evaporation on heating a body of water?
21. When water is heated, convection currents are set up. Why does this process retard the heating of a water body?
22. Why do water bodies act as regulators of air temperature?
23. Since land heats and cools faster than water, where should you expect extreme climates? Moderate climates?
24. On a clear, cold day, with snow on the ground, the temperature often remains low in spite of a bright sun. Why?
25. How is the atmosphere warmed by conduction?
26. What percentage of earth radiation is absorbed by the air? Mainly by what constituents of the air?

27. What is meant by the greenhouse effect of the atmosphere?

28. What is meant by convection? How does convection distribute temperature in the atmosphere?

29. What causes the "bumpy" air encountered by airplanes? Why is air more bumpy over land than over sea?

30. How does wind direction affect temperature?

31. Why does air become warmer when descending a mountain slope?

32. Why does the atmosphere usually cool at night?

33. What conditions promote rapid cooling of the atmosphere at night?

34. When is frost more likely to occur, on a clear or a cloudy night? Why?

35. What extreme day and night temperatures are sometimes experienced in the Sahara Desert? Why?

36. How is the atmosphere cooled by conduction? By winds?

37. Why does warm air cool as it rises? What is the rate of cooling?

38. How is mean daily temperature calculated? What is meant by daily range of temperature?

39. How is the daily range affected by mountains? Deserts? A cloud cover?

40. What is meant by the seasonal march of temperature?

41. What is meant by the lapse rate? What does it average?

42. What is the altitude of the stratosphere? What are its characteristics?

43. How does the troposphere differ from the stratosphere?

44. What is meant by air drainage?

45. What is one important result of air drainage?

46. Give an example of stable and unstable air.

47. What are the two meanings of the term *frost?*

48. What are the ideal conditions for frost formation?

49. What is one method of frost protection?

50. What is an isotherm?

51. Why are temperatures reduced to sea level on some world isothermal charts?

52. What are three general features of world-temperature distribution?

53. What are some significant features of temperature distribution shown by the isothermal charts for January and July?

54. What is meant by annual range of temperature? In what regions is the annual range greatest? Lowest?

Chapter III. Atmospheric Pressure and Winds

Compared with temperature and precipitation, atmospheric pressure and winds are relatively insignificant as elements of weather and climate. To be sure, winds of high velocity may be dangerous to man's crops and structures. There are, as well, certain physiological reactions to strong air movement. But the sum total of these direct effects of wind is not of first importance. Still less is human life directly affected by the slight changes in air pressure that occur at the earth's surface. Although imperceptible to our bodies, these pressure differences are the reason for the existence of winds. Therefore, although not directly of first importance as climatic elements, both pressure and winds are indirectly of outstanding significance in the effects that they have upon temperature and precipitation, the two genuinely important elements of weather and climate.

The sequence of events might be as follows: A minor change in pressure (of little consequence directly) acts to change the velocity and direction of wind (also not of major importance directly). This in turn brings about changes in temperature and precipitation, which together largely determine the character of weather and climate. Whether it is a south wind or a north wind is important because of the different temperature conditions induced by each. An onshore wind as compared with an offshore one is climatically significant because of differences in moisture and temperature. It is chiefly as controls of temperature and precipitation, then, rather than as elements of weather and climate that pressure and winds are worthy of attention. The most important single function of wind is the transportation of water vapor from the oceans to the lands, where that water vapor condenses and falls as rain.

Relation of Air Pressure to Temperature. A column of air 1 square inch in cross-sectional area extending from sea level to the top of the atmosphere weighs approximately 14.7 pounds. This weight is balanced by a column of mercury nearly 30 inches tall and having the same cross-sectional area. Thus it is customary to measure air pressure in terms of its equivalent weight as expressed in inches of a column of mercury—in other words, by a mercurial barometer. But the weight of a given volume of air varies with temperature. Thus when air is heated it expands and occupies more space, so that a column of warm light air weighs less than a column of cold heavy air, both having the same height and cross-sectional area. In central Asia in January, when temperatures are very low, the air pressure is nearly 1 inch of mercury greater than it is in summer.

It may be accepted as a general rule, therefore, that regions with high temperatures are likely to have lower air pressures than other regions where temperatures are not so high. In other words, high temperature tends to produce low pressure, and low temperature is conducive to high pressure. There are, however, some notable exceptions to the rule.

Distribution of Atmospheric Pressure

Vertical Distribution. Since air is very compressible, there is a rapid decrease in air weight or pressure with increasing altitude. The lower layers of the atmosphere are the densest because the weight of all the layers above rests upon them. In these lower layers of air, a mercury barometer drops about 1 inch for each 1,000 feet increase in elevation. With higher altitudes the air rapidly becomes much thinner and lighter; so that at an elevation of 17,500 feet, one-half the atmosphere by weight is below the observer, although the whole air mass extends to a height of several hundred miles. The human body is not physiologically adjusted to the low pressures and associated small oxygen content of the air at high altitudes. Nausea, faintness, and nosebleed often result from a too rapid ascent. Oxygen tanks are a part of the normal equipment of aircraft operating at high altitudes.

Horizontal Distribution. Just as temperature distribution is represented by isotherms, so atmospheric pressure distribution

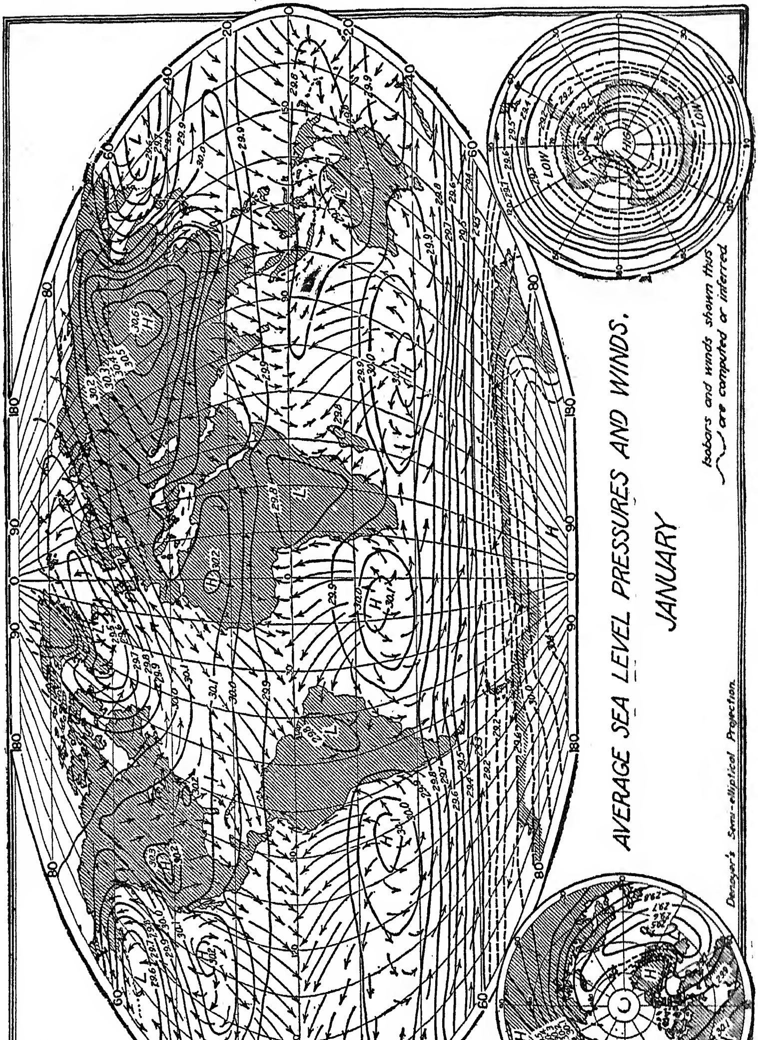
AVERAGE SEA LEVEL PRESSURES AND WINDS.
JANUARY
Isobars and winds shown thus are computed or inferred.
Denoyer's Semi-elliptical Projection.

FIG. 30.

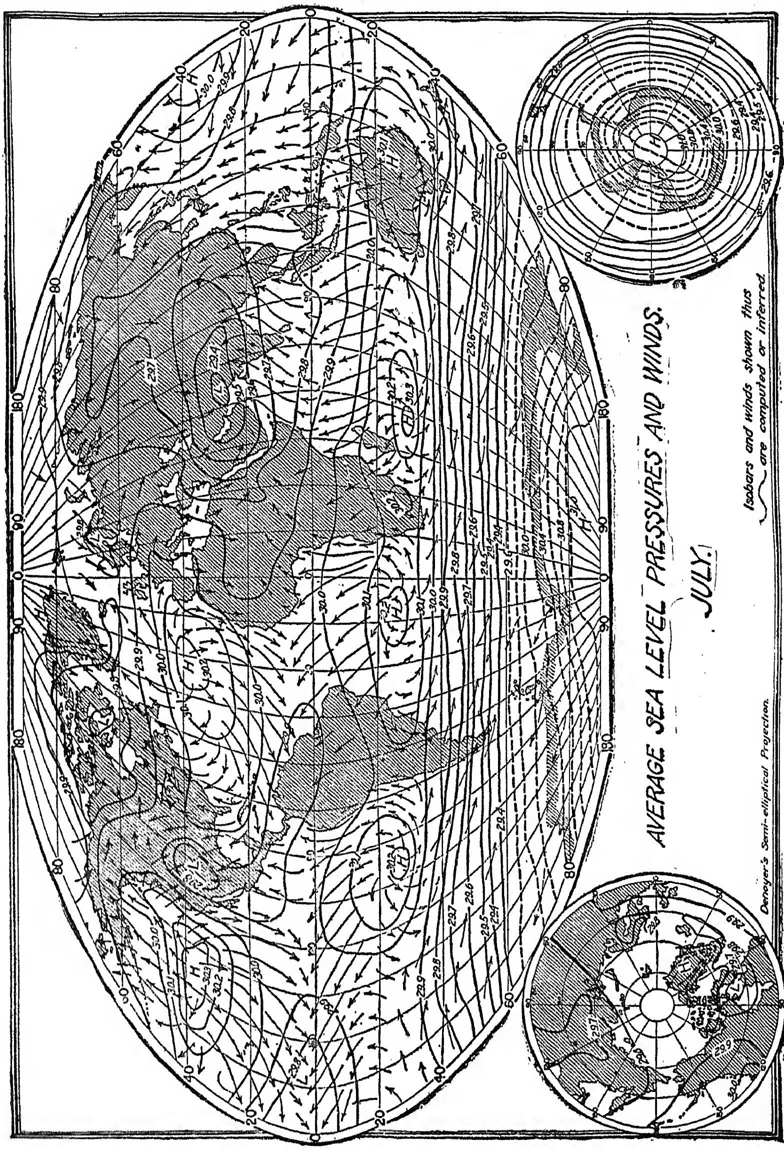
AVERAGE SEA LEVEL PRESSURES AND WINDS.
JULY.
Isobars and winds shown thus are computed or inferred.
Denoyer's Semi-elliptical Projection.

Fig. 31.

is represented by *isobars, i.e.*, lines connecting places having the same pressure. On the isobaric charts here shown (Figs. 30, 31), effects of elevation have been eliminated. All pressure readings have been reduced to sea level. This is necessary because pressure in high mountains and plateaus is always much less than at sea level. If these differences caused by elevation were not eliminated, it would be very difficult, if not impossible, to make world-wide comparisons of atmospheric pressure. Similar reduction to sea-level pressure is done also when drawing isobars on a daily weather map.

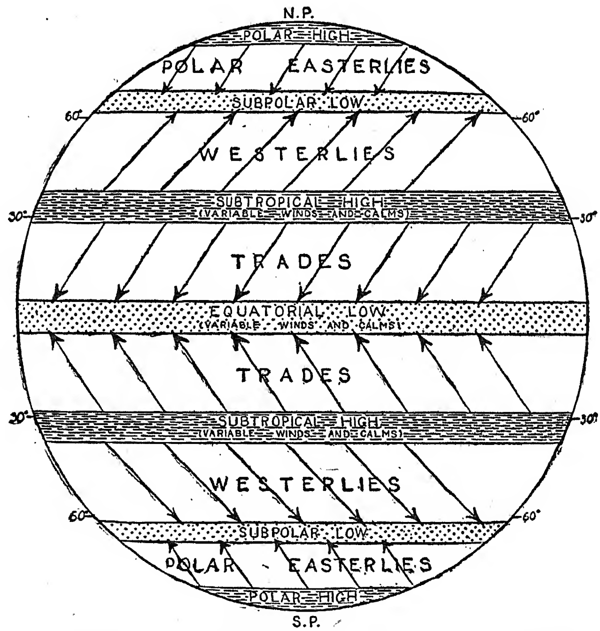

FIG. 32*A*.—A very diagrammatic representation of pressure and wind belts of the earth.

Figures 32*A* and 32*B* are diagrammatic sketches of pressure belts as they might exist on a globe composed of either all land or all water. This arrangement of pressure belts may be observed to some extent on the seasonal isobaric charts for January and July in the Southern Hemisphere where such a high percentage of the earth's surface is covered with water. In the Northern Hemisphere, great landmasses tend to disrupt the pressure belts.

The most noticeable features of average world-pressure conditions are as follows: (1) There is an equatorial belt of low

pressure (below 30 inches) which coincides rather closely with the belt of highest temperature. Within the belt the lowest pressures are over land, where the highest temperatures occur. (2) The subtropical highs (horse latitudes), a series of high-pressure centers, are located about 30° to 40°N. and S. Lat. (3) The subpolar troughs of low pressure are situated about 60° to 70°N. and S. Lat. This trough is much more continuous in the Southern than in the Northern Hemisphere. In the Northern Hemisphere it is represented by two distinct centers, the Iceland low in the North Atlantic and the Aleutian low in the North Pacific. (4) The polar highs in the vicinity of the North and South poles. It should be emphasized that equatorial low pressure is a result of high temperatures and that polar high pressure is a result of low temperatures.

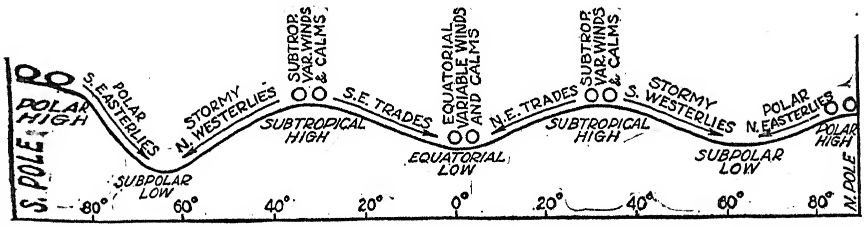

FIG. 32*B*.—A very diagrammatic representation of pressure and wind belts of the earth. Compare with Fig. 32*A*.

Profile of Average Pressure Distribution along a North-south Meridian. The general pressure conditions that have just been described are shown in a diagrammatic way in Fig. 32*B*. A line of "hills and valleys" drawn from pole to pole shows the points of high and low pressure. Above this line, by means of arrows which slope downhill, are shown the prevailing winds of the world. The curved line, or pressure profile, rises from the belt of low pressure near the equator to the subtropical highs at about 30° or 35°N. and S. Lat. Then it slopes downward to the subpolar lows in latitudes 60° to 70°, after which it rises again in the vicinity of the poles.

Isobars for January and July. Comparing the January and July maps, the following features may be noted: (1) The pressure belts, like those of temperature, move north with the sun's rays in July and south in January. They lag behind and do not migrate so far as do the insolation belts. Migration is greater

over continents than over oceans. (2) In winter the subtropical highs are strengthened by cold landmasses and are therefore more continuous; in summer they are weakened by the warm land areas. (3) Over landmasses, especially in Asia and North America, centers of low pressure develop in summer, and high pressure in winter. Pressure over adjacent oceans is just the reverse, huge low-pressure centers existing over the North Atlantic and North Pacific in winter.

Relation of Winds to Pressure

The Pressure Gradient. Air that moves essentially parallel to the earth's surface is referred to as *wind*. Vertical air movements are more properly designated as *currents*, although the name is often applied to horizontal movements as well. Wind is usually the result of horizontal differences in air pressure.

The *pressure gradient*, or *barometric slope*, refers to the rate and direction of the change in pressure. If pressure is low in Minnesota and high in Missouri, then the barometric slope is from south to north, and the wind will blow from south to north. If the difference in pressure between the two states is very great, then a steep barometric slope exists, and winds of high velocity will result.

Two fundamental rules concerned with the relationships existing between pressure and winds are: (1) The direction of air flow is from regions of higher pressure to regions of lower pressure, *i.e.*, down the barometric slope. This follows the law of gravitation and is just as natural as the well-known fact that water runs downhill. (2) The rate of air flow, or velocity of the wind, depends upon the steepness of the pressure gradient or the rate of pressure change. When the gradient is steep, air flow is rapid; and when it is weak, the wind is likewise weak. Just as the velocity of a river is determined largely by the slope of the land, or rate of change in elevation, so the velocity of wind is determined largely by the barometric slope, or the rate of change in air pressure.

One therefore can determine the steepness of the pressure gradient, and consequently the relative velocity of air movement, by noting the spacing or closeness of the isobars. Closely spaced isobars, like those in the vicinity of the subpolar trough

in the Southern Hemisphere, indicate relatively steep gradients, or marked pressure differences. Under these conditions winds of high velocity prevail. When isobars are far apart, gradients are weak, and winds are likewise. Calms prevail when pressure differences over extensive areas are very small. At such times there is nearly an absence of isobaric lines on the pressure map.

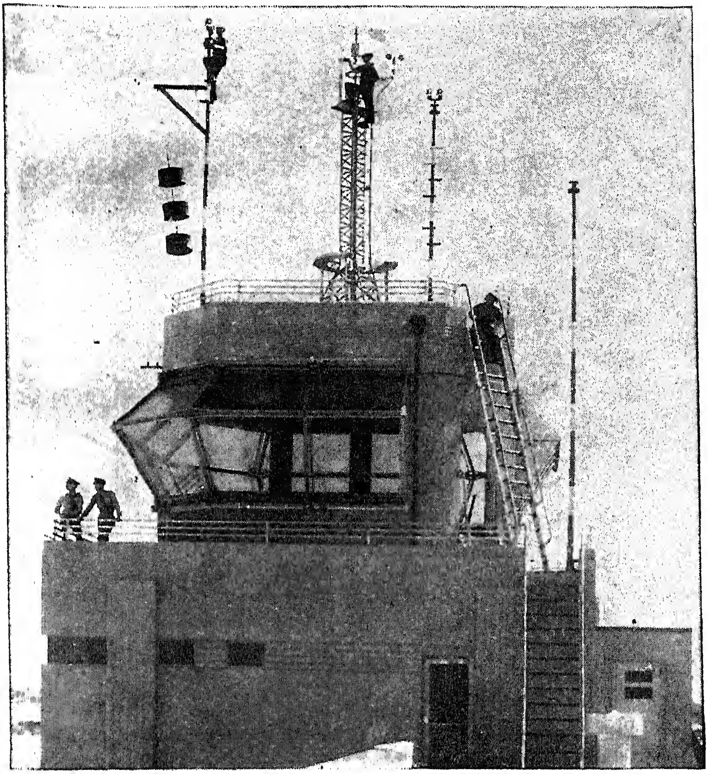

FIG. 33.—Navy personnel installing new aerological station on East Field Tower at Norfolk, Va. Anemometer cups appear to the right of the wind vane. (*Official photograph, U.S. Navy.*)

It should be borne in mind that winds are always named by the direction from which they come. Thus a wind from the south, blowing toward the north, is called a *south* wind. The wind vane points toward the direction from which the wind is coming (Fig. 33). It therefore points in a general way toward the high-pressure area down whose barometric slope the air is flowing. *Windward* refers to the direction from which a wind comes;

leeward, that toward which the wind blows. Thus a windward coast is one along which the air is moving onshore, and a leeward coast has winds offshore. When a wind blows more frequently from one direction than from any other, it is called a *prevailing* wind (Fig. 34). On the daily weather map, wind arrows fly with the wind.

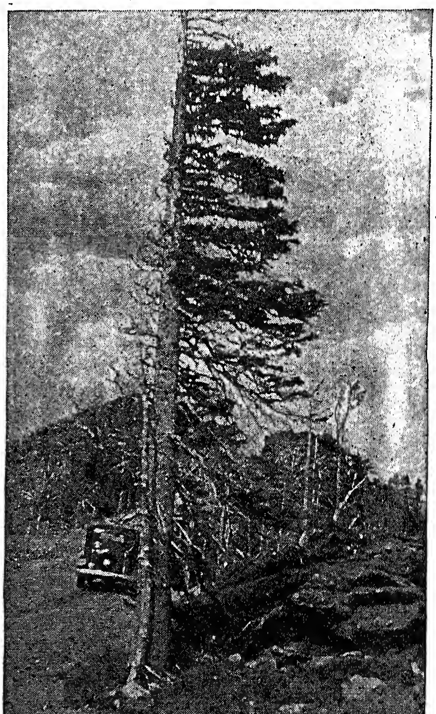

FIG. 34.—Prevailing winds often influence tree growth. Cold northwest winds in Rocky Mountain National Park, Colorado, have checked the growth of this tree on the side facing the wind. (*Photograph by Frank Banister.*)

Wind Direction and Velocity

Importance of Wind Direction. Wind directions as recorded by the weather bureau are usually limited to sixteen points of the compass at $22\frac{1}{2}°$ intervals beginning with north (Fig. 35). Ability to foretell wind direction a day ahead is a prime requisite of a good weather forecaster.

Suppose that a tropical air mass, moving as a south wind, is causing unusually warm weather in Des Moines, Iowa. The forecaster, by studying the weather map, foresees that on the following day a polar air mass, advancing from the northwest, will reach the city. Under such conditions he is certain to forecast colder weather. At another time, opposite conditions may exist.

Throughout the Central states, the prevailing wind direction in summer is south, owing to the prevalence of low pressure near the center of the North American continent; and in the winter northwest, owing to high pressure in the same locality. During January and February, 1936, a number of high-pressure areas with temperatures 40° to 50° below zero moved slowly over western Canada, Montana, and North Dakota, resulting in strong northwest winds over the Central states and the coldest winter in the history of many localities. Conversely, hot, dry air masses from the southwest often cause severe droughts in July and August, resulting in great damage to growing crops and causing much suffering among people and livestock. Wind direction foretells weather. Generally speaking, over much of central and eastern United States, easterly winds indicate the approach of foul weather; and westerly winds, fair weather.

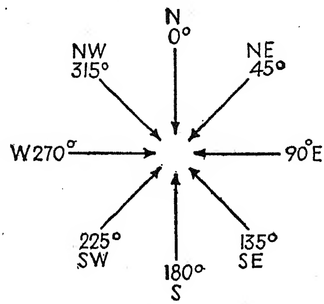

FIG. 35.—The eight principal wind directions.

Wind direction at high altitudes is ascertained by releasing rubber balloons filled with hydrogen and observing them through a small telescopic instrument (Fig. 36). Such balloon soundings also indicate velocity of winds aloft.

In the Central and Eastern states the upper winds are mainly from the southwest, west, and northwest and are usually much stronger, especially in winter, than surface winds (Figs. 37, 38). These upper winds partially account for the fast airplane flights from Los Angeles to New York.

Layers of air at different elevations often move in different directions. Thus an airplane pilot may find a strong head wind at 2,000 feet, whereas at 6,000 feet he might have a tail wind.

Two-way radio communication between airplane and airport often makes it possible for meteorologists to advise pilots in flight of the correct altitude at which to fly in order to take advantage of favorable wind direction. Obviously this service renders considerable savings in fuel consumption and in time.

FIG. 36.—Weather observer watching pilot balloon through a theodolite. He telephones data to a computer at the plotting board in the office. The data enable the computer to calculate the wind direction and velocity aloft. (*Courtesy of U.S. Weather Bureau.*)

Airplanes take off and land against the wind. A head wind causes the take-off to be more rapid; in landing a head wind acts as a brake, considerably lowering the landing speed of the plane (Fig. 39).

Wind velocity is measured in miles per hour by an instrument called an *anemometer* (see Appendix C). In general, winds are steadier over water than over land. Gusty winds are characteristic of landmasses. The surface velocity throughout the

Central states averages about 10 to 15 miles per hour but may range from zero to 60 or more.

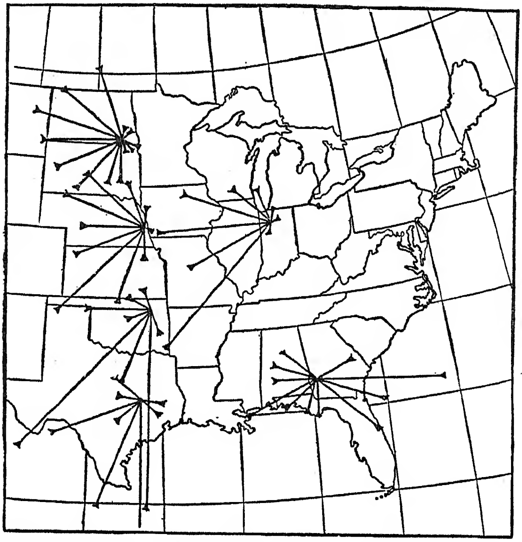

FIG. 37.—Prevailing directions of upper winds in summer. (*U.S. Weather Bureau.*)

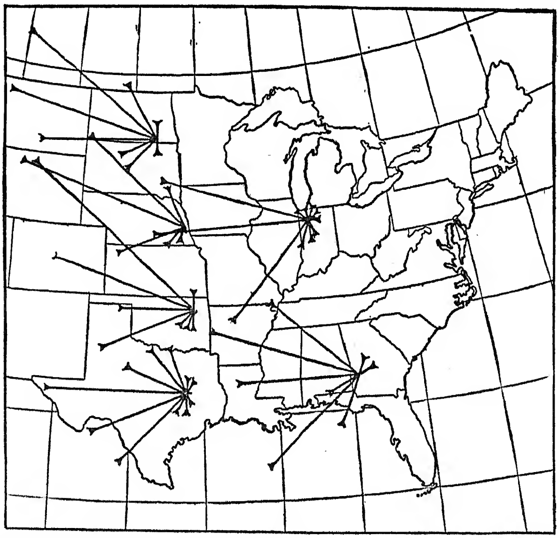

FIG. 38.—Prevailing directions of upper winds in winter. (*U.S. Weather Bureau.*)

Wind velocity is of tremendous importance in aviation. If an airplane has an air speed of 100 miles per hour and is going against a 100-mile wind, its speed over the earth's surface will

be zero, and from the ground it will appear stationary. If the wind increases to 110 miles per hour, the airplane will move backward at a speed of 10 miles per hour. If the pilot turns and goes with the wind, his speed over the earth will be 210 miles per hour. In many cases, however, the airplane encounters neither a direct head wind nor a tail wind. Instead, a side wind may be strong enough to carry the ship off its course. In such cases the pilot must head the nose of the ship into the wind in order to follow a given track over the earth's surface (Fig. 40). Taking advantage of strong upper winds, pilots have flown from California to New York at an average speed of over 250 miles per hour. Wind velocity is usually greater in high mountains than

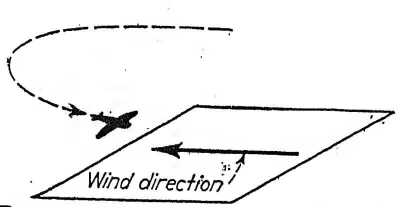

FIG. 39.—Airplanes land and take off against the wind. Why?

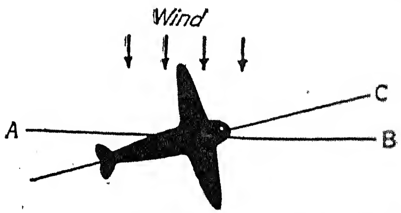

FIG. 40.—In order to fly in the direction represented by the line AB, the ship must head toward C to counteract wind drift. This is called *nosing into the wind.*

in lowlands. Low passes in the continental divide are well known for strong winds. One of the highest wind velocities ever recorded, 231 miles per hour, occurred atop Mt. Washington in northern New Hampshire in December, 1934.

The Earth's Wind Systems

PLANETARY SYSTEM OF WINDS

Planetary Winds. We have seen that, just as water flows from high to low elevations, so air flows from high to low pressure. Observe again Figs. 30, 31, and 33. From both subtropical high-pressure belts the air flows toward the equator. These are the *trade winds*. On the poleward side of the subtropical highs the air flows toward the subpolar troughs of low pressure. These winds are called the *stormy westerlies*. From the polar highs the *polar easterlies* blow toward the subpolar lows. Between the

trades, where pressure gradients are weak, is the equatorial belt of variable winds and calms called the *doldrums*. Between the trades and westerlies, at the tops of the subtropical highs, where pressure gradients are likewise weak, are the subtropical belts of variable winds and calms, sometimes called the *horse latitudes*.

Effects of Earth Rotation on Winds. The rotation of the earth on its axis causes the winds in the Northern Hemisphere to be deflected toward the right and in the Southern Hemisphere toward the left. Thus the trades become northeast winds *north* of the equator, and southeast winds *south* of the equator. The westerlies become mainly southwest winds in the Northern Hemisphere, and northwest winds in the Southern Hemisphere (Fig. 41).

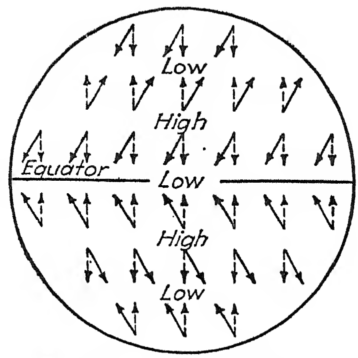

FIG. 41.—The solid arrows show the deflection of winds due to the earth's rotation. The rule is as follows: With one's back to the wind, deflection in the Northern Hemisphere is toward the right; in the Southern Hemisphere, toward the left.

THE SURFACE WINDS AND THEIR CHARACTERISTICS

Wind Belts and Centers of Action. It should be remembered that the system of world winds thus described holds true over oceans better than over landmasses. Heating and cooling of land and irregularities of the land surface tend to break up the generalized system of world wind belts. Isobaric charts of the world show certain centers of action, great semipermanent areas of high and low pressure over the oceans and continents with spiraling wind systems around them. Especially on the January chart the huge low-pressure area over the North Pacific Ocean (the Aleutian low) and another over the North Atlantic (the Iceland low) are clearly shown. On the same chart large areas of high pressure appear over North America and Asia. The "high" over Asia in January is intensified by the extreme cold of Siberia. In the Southern Hemisphere, on both the January and the July charts, centers of high pressure appear over the Indian, South Atlantic, and South Pacific oceans, and an unbroken belt

of low pressure extends around the world in the vicinity of the 70th parallel.

The centers of action are literally great wheels of atmospheric circulation, for it is they that generate the winds. Winds, in turn, largely determine the extent to which water vapor is carried from sea to land. Winds also influence the direction of ocean currents. It is evident that shifts in the position and intensity of these centers of action might have very marked effects upon the seasonal weather of any part of the earth. The study of these centers has been the basis of some attempts at long-distance weather forecasting.

Doldrums, or Equatorial Belt of Variable Winds and Calms. As the northeast and southeast trades converge toward the equator, they rise above the earth's surface, leaving between them at low elevations a condition of light and baffling breeze with much calm (Fig. 42). This doldrum belt therefore occupies the axis, or valley, of lowest pressure in the equatorial low-pressure trough where pressure gradients are weak and variable, resulting in winds of the same character. It needs to be emphasized that the nature of the winds is the result of the character of the barometric gradients. The condition of calms and variable winds is not clearly marked all round the equator, nor does it exist at all times of the year. In places and upon occasions it may be reduced to the vanishing point by the encroaching trades or by monsoons.[1]

The principal air movement in the doldrums is vertical rather than horizontal, ascending currents being indicated by the abundance of cumulus clouds,[2] numerous thunderstorms, and heavy convectional rainfall. Because this is a region of converging air currents that escape by upward movement, the doldrums are inclined to be turbulent and stormy, with calms, squalls, and light winds alternating. Within the doldrums, calms prevail 15 to 30 per cent of the time, and winds, chiefly light and gentle breezes, come from all points of the compass with about equal frequency (Fig. 42). Poor ventilation and sultry, oppressive weather are characteristic. In past times these regions were

[1] Monsoons are seasonal winds, blowing from sea to land in summer and from land to sea in winter. They are more fully explained in the latter part of this chapter.

[2] Cumulus clouds are described and illustrated in the next chapter.

rigorously avoided by sailing vessels. Owing to the fact that a sailing ship could very well be becalmed for days in the doldrums because of lack of wind, such boats often took longer routes and went far out of their courses in order to cross in the narrowest parts of the belt.

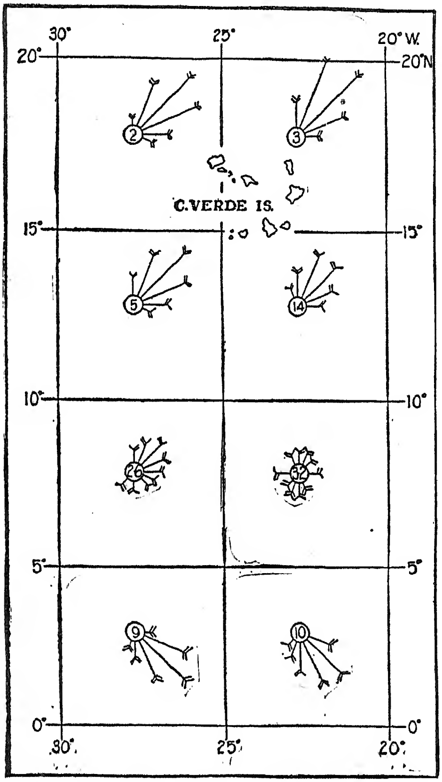

FIG. 42.—Northeast and southeast trades and doldrums over the Atlantic Ocean, June, 1922. The wind rose is given for each 5° square. Arrows fly with the wind. The length of the arrow is proportional to the frequency of winds from that direction. The number of feathers on the arrow indicates the average force of the wind. The numeral in the center gives the percentage of calms, light airs, and variable winds. (*U.S. Hydrographic Office Pilot Chart.*)

Although the doldrums are usually spoken of as a belt, it would be incorrect to conceive of this condition of variable winds and calms as having definite northern and southern boundaries. It merges imperceptibly with the trades on both margins over the oceans, so that its limits are often difficult to define. Irregular in width but averaging perhaps 200 to 300

miles, it extends in places for as much as 10° or more away from the equator. In other longitudes, especially where monsoons are well developed, as they are in the Indian Ocean, it may be wiped out entirely. Over the Atlantic Ocean in July, doldrums lie between latitudes 11°N. and 3°N., and in January between 3°N. and 0°. Most of the doldrum belt probably lies between parallels 5°N. and 5°S.

The Trade Winds. In each hemisphere these winds blow over the oceans approximately between latitudes 30° or 35° and 5° or 10°. They move obliquely downgradient from the subtropical high centers toward the equatorial low. Over the North Atlantic in summer the approximate limits of the northeast trades are 35°N. and 11°N.; in winter, 26°N. and 3°N. In parts of the low latitudes they reach, and even cross, the equator. Away from landmasses, trades blow rather constantly from an easterly direction (northeast in the Northern and southeast in the Southern Hemisphere). Over continents, and even adjacent to them, both steadiness and direction may be considerably modified. On the island of St. Helena, which lies in the heart of the southeast trades of the South Atlantic, the percentage of winds from various directions is as follows, according to Kendrew:[1]

	N.	*N.E.*	*E.*	*S.E.*	*S.*	*S.W.*	*Calm*
January	..	....	5	76	19		
July	1	2	9	62	20	1	5

Trades are the most regular and steady winds of the earth, particularly over the oceans. Their characteristic moderate to fresh breezes average 10 to 15 miles an hour. Calms are infrequent, usually prevailing less than 5 per cent of the time. Over landmasses and near their margins the surface trades are much less conspicuous. They blow with greater strength and constancy in winter than in summer, for in the hot season the belt of subtropical highs is broken by the heated continents, resulting in a much less continuous belt of trades at that season. Especially over eastern and southern Asia, and to a degree over the waters south and east of the United States as well, summer monsoons tend to weaken or even eliminate the trades. In

[1] Kendrew, W. G., *Climate*, p. 90, Oxford University Press, New York, 1938.

winter, on the other hand, outflowing continental winds tend to strengthen them. In general, the trades are regions of fine, clear weather with few storms. The most spectacular of these storms are the tropical hurricanes which infest their western equatorial margins over the oceans in the late summer and early fall.

The trades yield little precipitation when traveling over oceans or over landmasses of *low elevation*, so that they are often described as *desert makers*. But when these prevailingly "dry" winds are forced to rise abruptly, *e.g.*, along the elevated windward margin of a continent, they may yield copious rain. On one of the mountainous Hawaiian Islands, located in the northeast trades, annual rainfall on the windward side is over 200 inches, but on the leeward side it is less than 20 inches (Fig. 43).

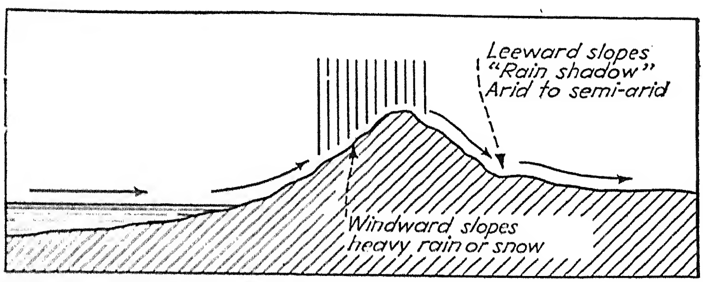

FIG. 43. When moist winds are forced to cross mountain barriers, heavy precipitation falls on the windward slopes, but leeward slopes are relatively dry.

Trade-wind Belts as Sailing Routes. Because of the steady nature of the trades, as well as their fine, clear weather with few severe storms, they were thoroughfares for sailing vessels. The routes of ships powered with either steam or Diesel engines are, of course, but little influenced by wind belts. Just as sailing craft avoided the belts of calms and fickle winds, so they sought out the trades and plotted their courses in order to take advantage of them. Thus, the charted route for wind-driven boats traveling from Europe to the United States ran southward along the Atlantic Coast of Europe and Africa to about latitude 25° or 30°, then due westward in the trades, and finally northward again in the western Atlantic (trace on Figs. 30, 31). This is much farther in miles than the more direct steamship route of today; but sailing craft measured their trips in days rather than in miles, and better time could be made by sailing

with the trades over a longer course than by fighting against the westerlies over a shorter route.

Columbus in his first voyage to the New World sailed south from Spain to the Canary Islands and then westward in the trades. His journal of the voyage contains frequent remarks concerning the fine weather and the favorable winds experienced. One notation describes the weather as being like April in Andalusia. The almost constant following winds from the northeast worried the sailors, however, for they feared that the return trip to Spain might be impossible. Upon one occasion when a westerly wind was experienced, Columbus wrote: "This con-

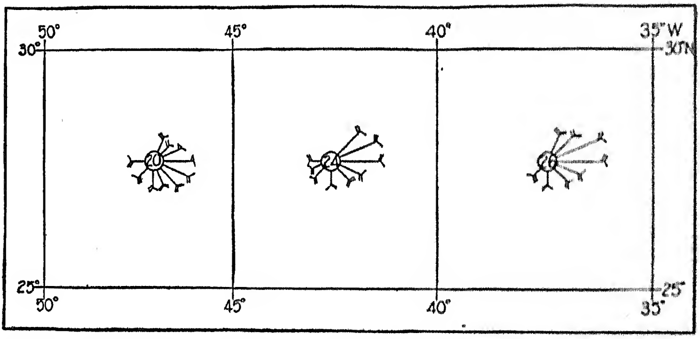

FIG. 44.—The subtropical "belt" of variable winds and calms, or horse latitudes, over the North Atlantic Ocean for June. Explanation of symbols is given below Fig. 42. (*U.S. Hydrographic Office Pilot Chart.*)

trary wind was very necessary to me, because my people were much excited at the thought that in these seas no wind ever blew in the direction of Spain."

The flying route from California to China via the Hawaiian and the Philippine Islands takes advantage of the fine weather of the trades. In flying west the trades are utilized as tail winds. On the return trip the ships fly at somewhat higher altitudes where the trades are weaker.

Subtropical Belts of Variable Winds and Calms, or the Horse Latitudes. Lying between the trades and stormy westerlies over the oceans are the horse latitudes. They occupy the crests of the high-pressure centers where pressure gradients are weak. Light, variable winds and calms therefore are the rule (Fig. 44). All regions with such wind characteristics must of necessity have weak pressure gradients. On the wind charts

(Figs. 30, 31) the horse latitudes are the centers of the great subtropical "whirls" of air, these whirls having opposite rotations in the Northern and Southern hemispheres. Although the horse latitudes are like the doldrums in their preponderance of light and fickle winds, blowing from any and all points of the compass, they are totally unlike them in their general weather conditions. Because they are regions of settling air and light, variable winds, the air is prevailingly dry. Skies are clear. The weather is fine much of the time. Sunshine is abundant and rainfall is relatively low. The centers or "ridges" of subtropical high pressure lie in the vicinity of latitudes 30° to 40°N. and S. These are sometimes known as the *Mediterranean latitudes*, because they correspond in location to that sea. The representative wind rose (Fig. 44) for these regions resembles that of the doldrums, calms prevailing 15 to 25 per cent of the time; and light and gentle breezes from all points of the compass, the remainder. The horse latitudes, like the doldrums, are avoided by sailing vessels.

Stormy Westerlies. Moving downgradient from the centers of subtropical high pressure to the subpolar lows (roughly 35° or 40° to 60° or 65°) are the stormy westerlies. Particularly is the poleward boundary of this wind belt a fluctuating one. It shifts with the seasons and over shorter periods of time as well.

The westerlies are distinctive among the wind belts in that they are neither uniformly strong nor weak but instead are composed of extremes. "Spells of weather" are one of their distinguishing characteristics. At times, and more especially in the winter, they blow with gale force; upon other occasions mild breezes prevail. Although designated as *westerlies* (westerly being the direction of most frequent and strongest winds), air does blow from all points of the compass (Fig. 45). The variability of winds, in both direction and strength, so characteristic of the westerlies, is largely the result of the procession of storms (cyclones and anticyclones) which travels from west to east in these latitudes. These storms tend to break up and modify the general westerly air movement. Moreover, on the eastern sides of Asia, and to a lesser degree North America, monsoon wind systems tend to disturb the westerlies, especially in summer.

It is in the Southern Hemisphere, where in latitudes 40° to 65° landmasses are largely absent, that the westerlies can be observed in their least interrupted development. Over these great expanses of oceans, winds of gale strength are common in summer as well as winter. These are the "roaring forties" of nautical jargon. In the vicinity of Cape Horn they are often

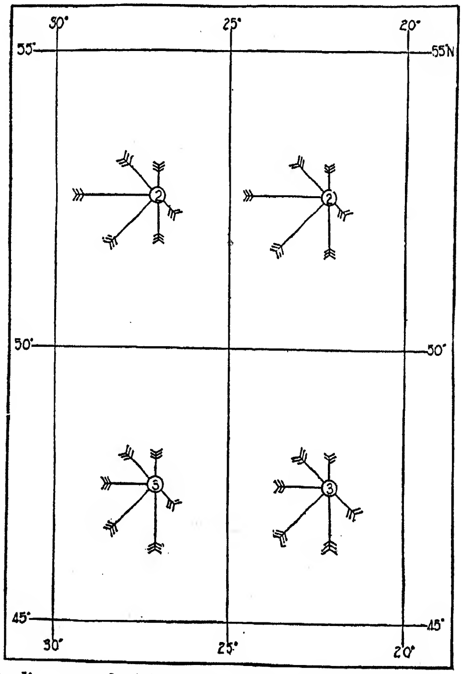

Fig. 45.—The westerlies over the North Atlantic Ocean in January. (*U.S. Hydrographic Office Pilot Chart.*)

so violent as to make east-west traffic around the Cape not only difficult but even dangerous. It is a wild region where gale follows gale with only brief intervening lulls; where raw chilly weather, cloudy skies, and mountainous seas prevail.

The westerlies of the Northern Hemisphere, where the great landmasses with their seasonal pressure reversals cause the wind systems to be much more complex, are considerably less violent in summer than in winter. In summer, gentle to fresh breezes prevail, and winds come from a great variety of directions with almost equal frequency. But winter winds are strong and boisterous, blowing mainly from westerly directions. In winter,

great masses of cold polar air occasionally move equatorward in the westerlies.

It is clear that the westerlies must be more difficult and strenuous sailing winds than are the trades, both because they are more stormy, and likewise because they are more variable in strength and direction. Although the winds are variable, they are strongest and most frequent from the west, so that sailing vessels plot their courses to take advantage of this condition. Thus sailing craft use the trades from Europe to America and the westerlies on the return trip. Similarly, in going from the United States or Europe to Australia, they go by the Cape of Good Hope, returning by Cape Horn.

Polar Winds. In the higher latitudes, beyond the belts of westerlies, the subpolar low-pressure troughs are extremely wild and stormy areas, for they are the routes followed by a large number of cyclonic storms of high latitudes. These storms, especially in the cool seasons, move southward into the paths of steamships plying the North Atlantic and North Pacific oceans. Winds of gale force together with huge waves often reduce the speed of an ocean liner. As a result, the ship's arrival at its destination may be delayed many hours.

Terrestrial Modifications of the Planetary Wind System

Causes of Terrestrial Modifications. Certain modifications of the idealized planetary wind system are due to (1) the inclination ($23\frac{1}{2}°$) and parallelism of the earth's axis, (2) the distribution of large landmasses in the Northern Hemisphere, and (3) shapes and elevations of landmasses.

Latitudinal Shifting of Wind Belts. The inclination and parallelism of the earth's axis as the earth revolves around the sun cause the sun's vertical ray to migrate from $23\frac{1}{2}°$N. (summer solstice, about June 21) to $23\frac{1}{2}°$S. (winter solstice, about December 21), a total of 47°. This in turn causes a north-south migration (of lesser extent) of the temperature, pressure, and wind belts. Some regions are thus influenced by two wind belts during the year. For example, between latitudes 5° and 15°N. and S., the doldrums may prevail during high sun, and the trades during low sun. Certain Mediterranean lands (latitudes 30° to 40°) experience the clear, dry weather of the horse lati-

tudes and trades in summer and the more stormy and wetter weather of the cyclonic westerlies in winter.

Monsoon Winds. Monsoon winds are the result of the earth's surface being composed of great land and water areas which have unequal heating and cooling qualities. Seasonal differences in temperature often give rise to seasonal contrasts in pressure; and, of course, contrasts in pressure give rise to changes in wind direction. The chain, or sequence, of events, then, is from temperature, through pressure, to winds.

In winter, for example, the interior of Asia becomes excessively cold, resulting in the development of a great stationary continental anticyclone or high-pressure center. Over the warmer seas to the east and south of Asia temperatures are higher, and the pressures consequently lower. As a result of this arrangement of the pressure areas, the surface gradient is from the continent toward the ocean. Consequently, cold surface winds move out from Asia toward the surrounding seas. This prevailing land wind constitutes the *winter monsoon* (January, Fig. 30). It is not always from the same direction in the various parts of eastern and southern Asia, for it blows from the west and northwest in Japan and North China and from the north and northeast in southern Asia, where it acts to strengthen the normal trade winds of those latitudes. But although not always from the same direction, it is, in almost all sections, a land wind, bringing cold, dry air down to the very sea margins and beyond. This condition is not conducive to rainfall, so that winter, or the period of low sun, is characteristically the driest season in monsoon lands. Winter monsoons, particularly of middle latitudes, are subject to interruptions by the passage of cyclonic storms which bring some precipitation even in the cool season.

Summer Monsoon. In summer the Asiatic continent becomes warmer than the adjacent oceans, and as a consequence a semipermanent seasonal low-pressure center develops over that landmass. Higher pressure prevails over the cooler oceans, so that the gradient is from sea to land, as are also the winds (July, Fig. 31). This mass of sea air moving in toward the heated continent is called the *summer monsoon*. Much of it originates in the trades south of the equator. Since it travels great distances

over bodies of tropical water, it brings with it abundant supplies of water vapor which are conducive to rainfall. Summer, therefore, is characteristically the wet season in monsoon lands. The summer monsoon is not always a wind from the same direction throughout southeastern Asia, but at least it is from the sea.

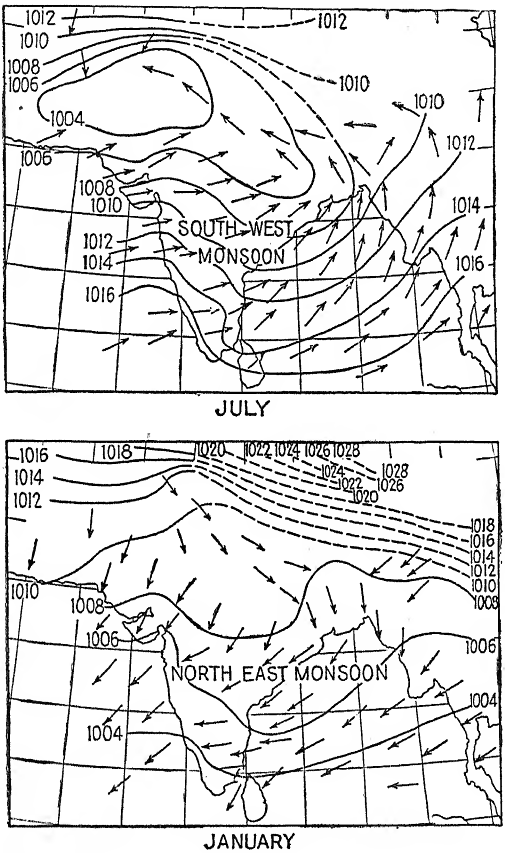

FIG. 46.—Seasonal pressures and winds over India.

Interruptions due to cyclonic storms are not infrequent. In monsoon regions continental-controlled winds tend to wipe out the planetary system of trades and westerlies, substituting in their places a terrestrial system. Hot, humid summers and relatively cold, dry winters are characteristic of most regions with continental wind systems in the middle latitudes. India, cut off as it is from the rest of Asia by high mountain ranges and

plateaus, has a monsoon system of local origin, quite distinct from that of the rest of the continent (Fig. 46). The following will help to fix the chain of events described above for a monsoon region:

Winter....Asia cold....high pressure.....winds toward sea.....dry season
Summer...Asia warm...low pressure.....winds toward land....wet season

Partly because of the great size of the continent, the monsoon system of winds is most perfectly developed over eastern and southern Asia, although monsoons in modified form, or monsoon tendencies, are characteristic of other regions as well (Fig. 47).

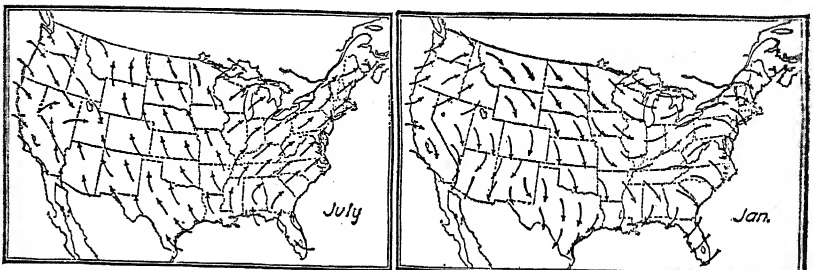

FIG. 47.—Seasonal winds over the United States. (*After Ward.*)

Southeastern United States, northern Australia, Spain, and South Africa all are regions with monsoon tendencies. These land areas may not always be sufficiently powerful to cause a complete seasonal reversal of winds as is Asia, but at least they create partial monsoons.

Land and Sea Breezes. Just as there are seasonal wind reversals (monsoons) resulting from seasonal temperature contrasts between land and water, so there are diurnal, or daily, monsoons resulting from similarly induced temperature contrasts within the 24-hour period. These are called *land and sea breezes*, or *diurnal monsoons*.

Thus along coasts there is often a drift of cool, heavy air from land to water at night (corresponding to winter) and a reversed wind direction, sea to land, during the heat of the day. Usually the sea breeze begins between 11 and 12 A.M. and seldom lasts much later than 4 in the afternoon. It is a shallow wind, penetrating only a short distance inland, usually not over 20 miles. Along tropical shores the sea breeze is a remarkably important climatic phenomenon, causing these places to be more livable

and healthful than they otherwise would be. The beginning of the sea breeze may cause a drop in temperature of 15° to 20° within $\frac{1}{4}$ to $\frac{1}{2}$ hour. Coasts with well-developed sea breezes are inclined to have modified marine climates, with the daily temperature extremes much reduced. The coasts of New Jersey and northern Chile are examples of regions having well-developed sea breezes in summer.

Mountain and Valley Breezes. Like land and sea breezes, these local winds have a distinct diurnal periodicity. During the day the air of an enclosed valley, or that adjacent to a slope receiving relatively direct rays of the sun, becomes heated so that active convectional ascent of the warm and expanded air takes place up the valleys and along the mountain slopes. This daytime updraft of warm air, or valley breeze, is indicated by the masses of cumulus clouds that collect about the peaks of mountains during summer days. They are the visible tops of invisible ascending air currents. Daily summer afternoon rains are therefore common in mountains, and visibility, because of the cloud masses, is restricted during the warm hours of the day.

After sundown, as the rapidly cooling slopes begin to chill the air layers next to them, the cooler, heavier air begins to slip down the mountain sides into the valleys (the principle of air drainage discussed in the previous chapter). This is a reversal of the day current and is known as the *mountain breeze*. It is often very perceptible at the mouth of a gulch. Where there are marked constrictions in a valley that drains a large area, strong winds may result. Summer camps are sometimes pitched at the mouth of a valley in order to benefit from the cooling effect and ventilation provided by the mountain breeze. The cool evening breeze attracts thousands of vacationists to mountain resorts in summer.

Winds and Ocean Currents. The slow moving of surface waters of the ocean (average rate about $2\frac{1}{4}$ miles per hour) is largely due to the friction of steady winds blowing over the water surface day after day. Thus the trade winds cause a slow drift of ocean water toward the west, both north and south of the equator, and the westerlies cause an eastward movement. A more detailed discussion of ocean currents is given in a later chapter.

Summary

Air has weight and therefore exerts pressure on all surfaces. Air pressure decreases about 1 inch per 900 feet increase in elevation. Isobaric charts indicate certain pressure belts on the earth. These pressure belts are directly related to the planetary winds of the world. Planetary winds greatly influence climate. They are modified in places by differences in temperature between land and water bodies.

Water evaporates into the air in the form of invisible water vapor. Winds carry water vapor from the oceans to the continents. This water vapor condenses to form clouds which in turn bring rain. Our next chapter, therefore, deals with atmospheric moisture and precipitation.

Questions

1. What is the most important function of the wind?
2. What is barometric pressure at sea level in inches of mercury? In pounds per square inch?
3. Which is heavier, warm air or cold air?
4. Why does a barometer rise and fall?
5. Normally, does high or low barometer result from high temperature? From low temperature?
6. Why do the lower layers of air have greater density than those at high altitudes?
7. How much does air pressure decrease with increase in altitude?
8. One-half the atmosphere by weight is within how many feet of the earth's surface?
9. Define isobar.
10. Why is the ideal arrangement of wind belts more easily recognized in the Southern than in the Northern Hemisphere?
11. What are the four most noticeable features of average atmospheric pressure over the earth's surface?
12. What is wind? What causes wind?
13. Define pressure gradient.
14. State the two fundamental rules dealing with the relationship between pressure and winds.
15. How do isobars help to indicate wind velocity?
16. Define windward, leeward, prevailing wind.
17. What is the prevailing direction of the wind in the Central states in summer? Why? In winter? Why?

18. During droughts in the United States, what are the prevailing wind directions?

19. How are direction and velocity of upper winds ascertained?

20. What are the prevailing directions of upper winds in the Central and Eastern states? How does wind velocity usually change with increase in altitude?

21. Why is a knowledge of upper winds so important to an airplane pilot?

22. Why does an airplane take off and land against the wind?

23. What is an anemometer?

24. Why are winds steadier over water than over land? Give two reasons.

25. What is the average wind velocity in the Central states?

26. In aviation, what is meant by a head wind? Tail wind? Side wind?

27. Why is wind velocity important in aviation?

28. Where is Mt. Washington? What wind velocity has been recorded there?

29. Name the planetary winds.

30. How are they deflected by the earth's rotation?

31. Why are wind belts less continuous in the Northern than in the Southern Hemisphere?

32. Where are the two principal low-pressure "centers of action" in the Northern Hemisphere? Give their names.

33. In the doldrums, what is the nature of winds? Of rainfall?

34. Why did sailing vessels avoid the doldrums when possible?

35. Most of the doldrum belt probably lies between what parallels?

36. What is the approximate latitude of the trade winds? From what direction do they blow south of the equator? North?

37. In general, trade-wind regions have what kind of weather?

38. Where do trades produce copious rainfall?

39. Why were the trade winds favorable to sailing vessels?

40. What are the longitude and latitude of the Hawaiian Islands? They are in which wind belt? Which mountain slopes receive heavy rain?

41. What route is followed by sailing vessels across the Atlantic? By airplanes from California to China? Trace on a map.

42. What is the nature of winds in the horse latitudes? Describe the weather in these regions. Why is it relatively dry?

43. What parts of what continents are in the stormy westerlies?

44. Describe wind behavior in the stormy westerlies. Why such a great variability in direction and velocity?

45. In what latitudes are the westerlies least interrupted?

46. Where are the "roaring forties"? What is the nature of weather there?

47. What is the general nature of polar winds?

48. What is meant by "latitudinal shifting of wind belts"?

49. What causes the winter monsoon of Asia? Effects on temperature?

50. Why is winter the dry season in monsoon regions?

51. What causes the summer monsoon of Asia?

52. Why is summer the wet season in monsoon regions?

53. Why does India have a monsoon wind system of local origin?

54. North America has a monsoon tendency. Is such influence more noticeable on the East or West coast? Why?

55. Explain the cause of land sea breezes. Where do such breezes influence daily weather in the United States?

56. What is the cause of mountain and valley breezes?

57. What is probably the principal cause of ocean currents?

Suggested Activities

1. On a map of the world, draw arrows to indicate wind "belts." Show a few routes of sailing vessels with red lines and steamship routes with blue lines. Explain some of the contrasts shown. Use another color for principal air lines.

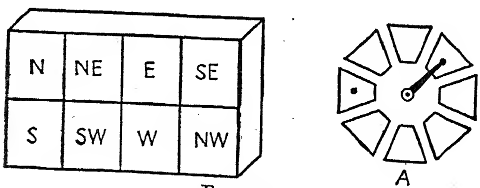

Fig. 48.

2. Construct an electrical indicator for wind direction. In a box about 12 by 20 inches and 3 inches deep build partitions to divide the space into eight equal parts. Place a small electric light in each pocket. Over the top of the box fasten a piece of translucent glass with the wind directions shown as in Fig. 48. On the roof, build an eight-pointed switch as shown at *A*. At the center is the upright rod of a wind vane. A sliding contact is fastened to the upright rod and moves over the eight segments as the wind vane changes direction. Run a cable of nine wires from the eight-pointed switch to the box of lights in the laboratory.

Build an anemometer such that the center rod that supports the cups rotates with the cups. On the center rod arrange an electrical switch in such a way that when the cups rotate sufficiently, elec-

trical contact is made, closing a circuit that causes a light in the laboratory to flash. The number of flashes per minute will provide an idea of wind velocity.

3. If a barograph is not available, record the barometer readings every hour, and plot a curve to show changes in atmospheric pressure during the day.

4. Find out the elevation above sea level of your school building. Reduce the barometer reading to sea level by adding the necessary amount. Do the same for Denver, Salt Lake City, Yellowstone Park, and Pike's Peak. This is the necessary procedure in construction of the daily weather map.

5. If possible, visit an airport. Observe the care with which wind velocity and direction are recorded. At the larger airports you may hear the radio operator advising a pilot in the air to fly at a certain altitude in order to take advantage of favorable winds.

NOTE: Other activities may be found in the laboratory manual.

Topics for Class Reports

1. Local Conditions of Atmospheric Pressure and Winds
2. Results of Upper Air Observations in the United States
3. Pilot Charts of the Various Oceans (U.S. Hydrographic Office)
4. The Use of Air Pressure in Ascertaining Altitude
5. Balloon and Airplane Soundings of Upper Air Conditions
6. The Monsoon Winds of India
7. The Routes of Sailing Vessels
8. The Contrasting Weather Conditions in the Trades and Westerlies
9. Contrasting Pressure Gradients in Summer and Winter (See U.S. Weather maps)
10. Windward and Leeward Coasts of South America

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Chapter IV. Atmospheric Moisture and Precipitation

The composition of the atmosphere is fairly constant from time to time and place to place. The amount of water vapor in the air, however, is by no means uniform, since it varies from nearly zero to almost 5 per cent. This variability is of outstanding importance for the following reasons: (1) The amount of moisture in the air is directly related to rainfall possibilities. (2) Water vapor absorbs energy radiated from the earth and thus tends to regulate temperature. (3) The greater the amount of water vapor in the air the greater the quantity of stored-up energy for the production of storms. (4) The amount of water vapor is likewise an important factor affecting the human body's rate of cooling, *i.e.*, the sensible temperature.

Sources of Water Vapor. Like all the other gases in the atmosphere, water vapor is invisible. The primary source of this important gas is the great oceans which cover approximately three-quarters of the earth's surface. By winds and diffusion methods, the water vapor evaporated from these bodies of water through the expenditure of solar energy is carried in over the continents. Less important, but nevertheless significant, sources of atmospheric moisture are the moist land surfaces, the vegetation cover, and the minor bodies of water. Plants give off more moisture to the air than does bare ground but not so much as a freely exposed water surface. A constant turnover is forever in progress as regards the atmosphere's water vapor, additions being made through evaporation of water in its solid and liquid states, while some is being lost to the atmosphere by condensation. As winds carry the moisture in gas form from the oceans to the land, so rivers and glaciers deliver it again in

liquid or solid form to the seas. Half the water vapor in the air lies below an altitude of 6,500 feet.

Evaporation and Condensation. *Evaporation* is the changing of a liquid to a gas. Some solids, such as ice, evaporate. The rate of evaporation of water depends upon (1) the temperature of the water, (2) the temperature of the air that is in contact with the water, (3) the amount of water vapor already in the air, and (4) the velocity of the wind. *Condensation* is the changing of a gas to a liquid or solid. Water vapor, which is invisible, condenses into a visible liquid form (cloud) when air is sufficiently cooled (Fig. 49). These processes are well illustrated by an airplane in flight. In one stratum of air having a temperature a few degrees below freezing and containing some water in liquid form, moisture may condense in the form of ice on the leading edge of the wing; in another stratum the ice may evaporate rapidly. It is evident that the two strata differ in the quantity of water vapor present.

Latent Energy in Water Vapor. Heat and motion are forms of energy. Heat energy is required to change water in the liquid form into steam or water vapor. The unit of heat energy, the calorie, is the amount of heat required to raise the temperature of 1 gram of water 1°C. It takes 80 calories to convert a gram of ice into a gram of water at freezing temperature. A much greater quantity of heat, 607 calories, is required to evaporate a gram of water at 32° into water vapor at the same temperature. Thus it is evident that water vapor contains more potential energy than the liquid form. This stored-up energy is called *latent heat.* For the most part it is transformed sun energy which was employed in evaporation. One reason why bodies of water heat slowly is that so much energy is consumed by evaporation at the surface. That evaporation requires heat is evident from the cool sensation experienced when the skin is moistened with water or, better, gasoline or ether. In this case heat is subtracted from the skin to convert the liquid into a gas. If energy is consumed in the process of evaporation, then, conversely, energy should again be released during condensation. *Latent heat of condensation* is the heat released by the condensation of water vapor, especially in the formation of clouds. This heat increases the strength of convection currents in the center of a storm,

thus increasing the intensity or severity of the storm itself. On a cloudy night when condensation is taking place, latent heat of condensation aids in preventing the normal cooling of the lower layers of air.

Humidity

The amount of water vapor that air can hold depends largely upon its temperature. *Capacity* is the maximum amount of water vapor that a cubic foot of air can hold at a given temperature.

MAXIMUM WATER-VAPOR CAPACITY OF 1 CU. FT. OF AIR AT VARYING TEMPERATURES

Temperature, Degrees Fahrenheit	*Water Vapor, Grains*	*Difference between Successive 10° Intervals*
30	1.9	
40	2.9	1.0
50	4.1	1.2
60	5.7	1.6
70	8.0	2.3
80	10.9	2.9
90	14.7	3.8
100	19.7	5.0

It is evident from the foregoing table that warm air is capable of holding much more water vapor than cold air. Warm air, therefore, has greater potentialities for producing abundant rain than does cold air. Air is said to be *saturated* when it contains all the water vapor possible. Water vapor, at the same temperature and pressure, is lighter than air in the ratio of 5 to 8. Very humid air is, therefore, lighter than dry air. Moist air consequently is less able to support the weight of smoke particles than is dry air at the same temperature.

Absolute humidity is the actual amount of water vapor in the air measured in grains per cubic foot (or grams per cubic meter). This amount is usually greatest in the vicinity of the equator and decreases toward the poles, varying considerably, however, with distance from the ocean and smaller bodies of water. Masses of air differ greatly in absolute humidity. This is especially noticeable in winter. A tropical air mass, originating

over the Caribbean Sea or the Gulf of Mexico and moving north, usually has a high absolute humidity, whereas a polar air mass, moving from northern Canada toward the south, contains much less water vapor per cubic unit. Absolute humidity is usually very low when an air mass from northern Mexico, New Mexico, and western Texas moves from the southwest toward the Central states. This air from the southwest may carry much dust. At such times both absolute and relative humidity are very low, owing partly to the absorption of moisture by the dust. During one dust storm in March, 1936, the relative humidity at Kansas City, Mo., was 8 per cent at 11 P.M., a time of day when relative humidity often is in the neighborhood of 80 per cent.

Relative humidity is the percentage of water vapor in the air and is determined by the ratio of absolute humidity to capacity. Stated in another way, relative humidity may be said to be an expression of the relationship between the actual amount of water vapor in the air (absolute humidity) and the total amount of water vapor that the air could hold at the same temperature (capacity). For example, air at 70°F. can contain approximately 8 grains of water vapor per cubic foot (its capacity). If, however, it contains only 6 grains (its absolute humidity), then it is only three-fourths saturated, and its relative humidity is 75 per cent. Whenever temperature of the air changes, capacity also changes, and therefore relative humidity. This is illustrated by the following figures:

Temperature, Degrees F.	*Absolute Humidity, Grains*	*Relative Humidity, Per Cent*
40	2.9	100 saturated
50	2.9	71 saturated
60	2.9	51 saturated
70	2.9	36 saturated
80	2.9	27 saturated
90	2.9	19 saturated

The relationship existing between absolute humidity (*AH*), capacity (*C*), and relative humidity (*RH*) may be expressed by

the following formula:

$$RH = \frac{AH}{C} \text{ (expressed in percentage)}$$

If air that is not saturated is sufficiently cooled, thereby reducing its capacity for moisture, a temperature is eventually reached at which the mass of air is saturated. The *dew point* is the temperature at which the air is saturated and below which condensation takes place. Thus air at 90° that contains 5.7 grains of water vapor per cubic foot (its absolute humidity) has a dew point of 60° because 5.7 is capacity at 60°. Further cooling below the dew point causes condensation, forming minute water particles (cloud or fog) if above 32° and ice crystals if below 32°. Suppose that this air is cooled to 40°. The amount of water vapor condensed per cubic foot is $5.7 - 2.9 = 2.8$ grains (see table, page 80).

Much moisture is condensed when warm, saturated air is cooled. Comparing warm and cool air, the following may be noted: saturated air at 90° cooled 20° yields 6.7 grains per cubic foot; saturated air at 50° cooled 20° yields 2.2 grains per cubic foot.

Problem 1. Air at 70° has a relative humidity of 72 per cent. What is the absolute humidity? The dew point?

$$\begin{aligned} AH &= RH \times C \qquad \text{Capacity at } 70° = 8.0 \\ &= 0.72 \times 8.0 \\ &= 5.76 \text{ grains per cubic foot} \end{aligned}$$

According to the table of capacities, this air would be saturated if its temperature were reduced to 60°. The dew point is therefore 60°.

Problem 2. Outdoor air at 30° with a relative humidity of 80 per cent is brought indoors and heated to 70° without the addition of any water vapor. What is the relative humidity indoors?

$$AH = RH \times C \qquad AH = 0.80 \times 1.9 = 1.52$$

Temperature indoors is 70°; therefore $C = 8.0$

$$RH = \frac{1.52}{8.00} = 19 \text{ per cent indoors}$$

Problem 2 illustrates a condition that too often exists in our homes and public buildings in winter. Relative humidity of

19 per cent indicates very dry air which, together with dust, causes inflammation of the tender membranes of the nose and throat, possibly making us more susceptible to contagious diseases of many kinds. Since dry air causes more rapid evaporation of moisture from the body, with the resulting cooling effects, it follows that increased humidity would improve the quality of the air from the standpoint of human comfort. For these reasons and others, effort should be made to add moisture to the air indoors in winter. Some furnaces are equipped with humidifiers. Evaporating pans can be placed at suitable places.

In the summer, especially in our Central and Eastern states, relative humidity is often abnormally high, causing us to be extremely uncomfortable. We speak of such weather as "muggy," or "sticky." On such days, indoors, we should seek not only to cool the air but to reduce its water vapor content.

Air conditioning involves those methods by which air is brought to and kept at the most desirable temperature and humidity for the comfort of the human body. Such conditioning includes the following: (1) filtration of the air, (2) disinfecting, (3) regulation of temperature, (4) regulation of humidity, (5) circulation, and (6) proper insulation of the building. Many modern homes are equipped with air-conditioning units. Certain railroads are featuring fast, streamlined, air-conditioned trains. Steamship companies whose vessels travel in tropical waters are offering as an added attraction air-conditioned sleeping quarters aboard ship. It is a rather remarkable fact that the people of a large city will spend considerable sums of money for the heating of homes in winter but that relatively small expenditures are made for cooling in summer. And yet in that same city deaths from heat prostration may actually exceed those caused by severe cold.

Condensation

What Causes Condensation. The only known method whereby water vapor in the atmosphere can be converted into the liquid or solid state (condensation) is to reduce the temperature of the air below the dew point. When air is cooled, its capacity for water vapor is lowered; and if the cooling is sufficient, condensation of water vapor must result. The dew point

of any mass of air is closely related to its relative humidity. When the relative humidity is high and the air is close to the saturation point, only a slight cooling is necessary for the dew point to be reached and for condensation to begin. On the other hand, when relative humidity is low, as it usually is over the hot deserts, a large amount of cooling is required before the dew point is reached. Condensation, therefore, depends upon two variables: (1) the amount of cooling and (2) the relative humidity of the air. If the dew point is not reached until the temperature falls below 32°, the condensed water vapor may be in the form of tiny ice crystals (white frost, snow, and some clouds); if condensation occurs above the freezing point, it will be in the liquid state (dew, fog, and most clouds).

Methods of Cooling the Atmosphere and Resulting Forms of Condensation

Quiet Air in Contact with Cold Earth's Surface. Day and night the earth radiates its heat into space. If the surface cools, the air in contact with it also cools, owing largely to conduction of heat from the lower layers of air to the earth. Clear skies and dry air are relatively essential to this process, since they permit rapid loss of heat from the earth. Windy nights are not conducive to surface cooling, for under these conditions there is a constant "churning" of the lower air so that it does not remain long enough in contact with the earth's surface to be markedly cooled. Moreover, the cooling is distributed throughout a larger mass of air. It is a well-known fact that both dew and frost are much more likely to occur on nights that are clear and calm than on those when the sky is overcast and a wind is blowing. Condensation may take place throughout a shallow layer of surface air, producing a fog. Such fogs are particularly noticeable in lowlands, where, as a result of air drainage, the colder, heavier air has collected. Fogs of this nature are called *radiation*, or *lowland*, fogs. From a hilltop one may observe "lakes" of fog, or patches of frost, occupying the surrounding depressions. As the sun rises, these lowland fogs usually are quickly evaporated. The famous London fogs are of this type, the chilled air collecting in the Thames lowland. Their darkness and persistence are a result of a "lid" of smoke and soot which

prevents the penetration of sunlight which would cause evaporation of the moisture particles.

Dew is formed when water vapor condenses on the earth's surface and the temperature is above 32°. Dew forms quickly on grass mainly for two reasons: (1) Transpiration of water from the grass increases the relative humidity of the air near the ground, assuming a calm night. (2) The millions of blades of grass offer a tremendous surface from which heat is radiated, thus lowering

FIG. 49.—Stratus clouds and advection fog, seen from Mt. Wilson, California. (*Photograph by F. Ellerman.*)

the temperature below the dew point. Drops of water condensed on the outside of a pitcher of ice water illustrate the formation of dew. The approximate dew point of the air can be found by noting the temperature of the water inside the pitcher at the moment when condensation first begins on the outside surface. White frost is formed when condensation occurs below 32°. For the most part, frost consists of delicate ice crystals resulting from the direct change of water vapor to ice. A similar change at high altitudes causes the formation of snow. There are times, on the earth's surface, when the temperature drops below 32° but does not reach the dew point, and no white frost appears.

Nevertheless, a frost has occurred. This type is called a *dry freeze*.

Moist Air Moving over Cold Surfaces. This process of cooling the air produces relatively widespread, dense, and persistent fogs, the type that seriously hinders aviation. Such are known as *advection* fogs (Fig. 49). Especially in winter, moist air from the south may blow over the cold, often snow-covered land, resulting in fog formation. The dense fogs along the California coast are largely due to the chilling of moist ocean winds as they pass over a belt of upwelling, cold water near shore. Fogs over the Great Lakes often result, especially in spring, when warm winds from the land blow over the colder water. In the region of the Grand Banks off Newfoundland, the Gulf Stream, a warm ocean current, comes near the cold Labrador Current. Extremely dense fogs result, as the relatively warm air from over the Gulf Stream drifts over the colder water of the Labrador Current (Fig. 50). Cool ocean currents along the coasts of Chile and southwest Africa are largely responsible for fogs in those regions.

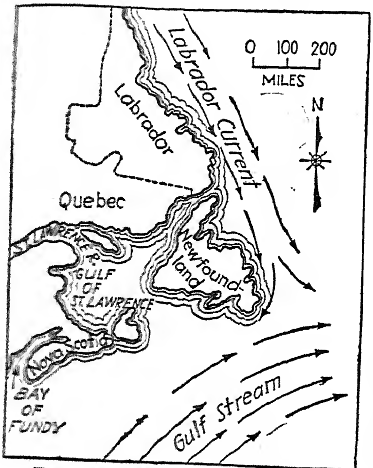


FIG. 50.—The cold Labrador Current and relatively warm Gulf Stream are largely responsible for the dense fogs in the vicinity of Newfoundland. It is the Labrador Current that carries icebergs south into the paths of ocean liners. Observe the location of the Bay of Fundy, noted for its extremely high tides.

Cooling Resulting from Expansion of the Air in Rising Currents. When air rises, no matter for what reason, it expands, because there is less pressure upon it at the higher altitudes. At 17,500 feet, pressure is about one-half that at sea level. As the air rises and expands, it cools at the rate of about 5° per 1,000 feet. This rate of cooling is much more rapid than that shown when a thermometer is carried upward through the atmosphere (about 3.2° per 1,000 feet). When air descends, it is compressed by the denser, lower layers, and as a result its temperature increases.

Ascending air currents → expansion → cooling
Descending air currents → compression → warming
Cooling air → capacity for water vapor decreases → condensation
Warming air → capacity for water vapor increases → evaporation

Heated air continues to rise until it reaches air layers of its own temperature and density. This process of cooling, by expansion of rising air currents, is the only one capable of reducing the temperature of great masses of air below the dew point, thereby causing condensation of water vapor on such a large scale that abundant precipitation results. As air rises, it finally reaches an altitude where condensation of the water vapor present takes place, forming clouds. A *cloud* consists of billions of tiny water particles, so light in weight that they are easily carried from place to place or from low to high altitudes by winds and air currents. Clouds often are composed of tiny ice crystals (snow) in winter and at high elevations in summer. Fog and cloud are identical except for differences in height above the ground. Not all clouds give rise to precipitation, but all precipitation has its origin in clouds and is the result of exaggerated condensation processes taking place within them.

Cloud Particles and Light Rays. When light rays pass from air into water they are reflected at the surface and refracted (bent) as they pass through. Thus the colors of the solar spectrum (violet, indigo, blue, green, yellow, orange, and red) are brought out by the *rainbow*, caused by refraction and reflection of sunlight acting on multitudes of water particles in the air. The action of moonlight on water and ice particles in the upper air is responsible for the *halo* of the moon. Beautiful colors of sunrise and sunset are due to the breaking up of sunlight not only by moisture but also by dust particles in the atmosphere. These colors are more brilliant in the morning and evening because there are far more dust and water particles between the eye and the sun at those times of day than, let us say, at noon.

Cloud Types. Four principal, or pure, cloud types are usually recognized. The other numerous types that can be observed are modifications or combinations of these four.

Cumulus. These relatively fair-weather clouds are distinguished by their flat bases and their beautiful, towering, cauliflower tops (Figs. 51, 52). The flat bases mark condensation

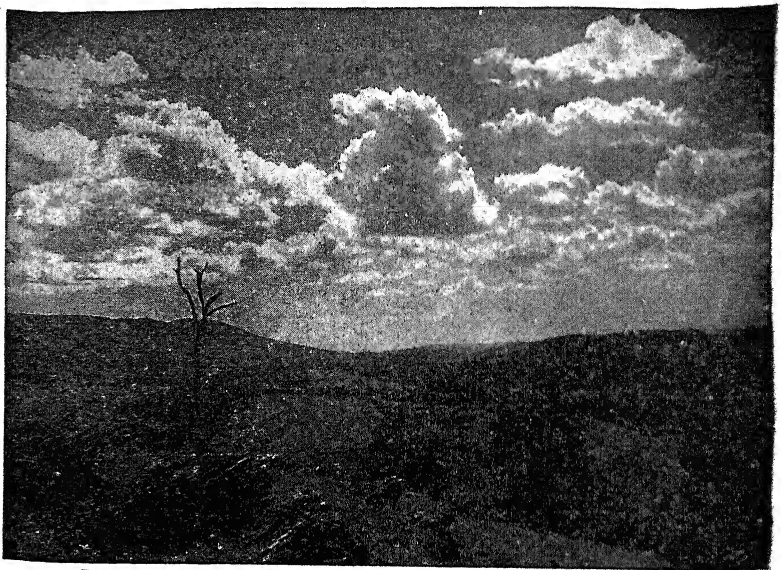


FIG. 51.—Cumulus clouds. (*Photograph by L. W. Humphreys.*)

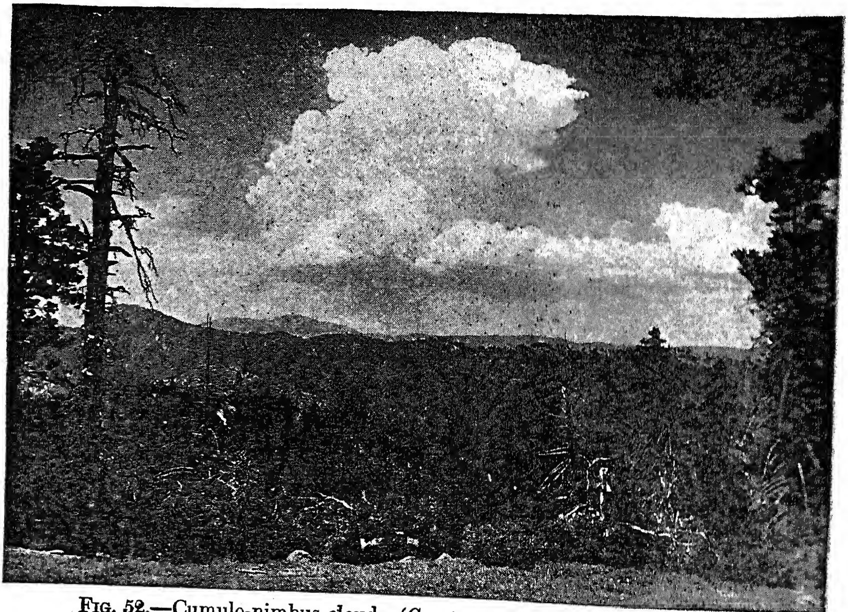


FIG. 52.—Cumulo-nimbus clouds. (*Courtesy of U.S. Weather Bureau.*)

level. Cumulus clouds are the result of vertically ascending air currents and are usually associated with local surface heating on warm summer days. Of course, convectional ascent does not take place over the entire heated surface. In some places warm air masses are rising; in others cooler air masses are settling to the earth. Thus separate and isolated cumuli occur with patches of blue sky between. Sometimes on hot, humid days

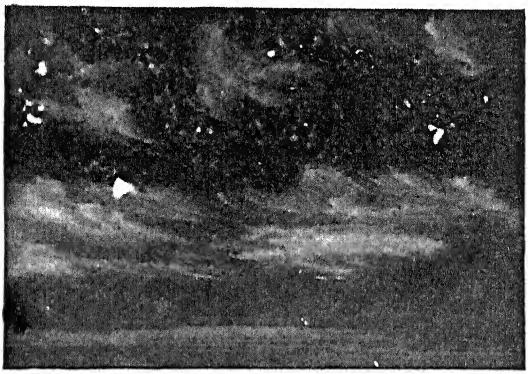


FIG. 53.—Cirrus clouds. (*Courtesy of U.S. Weather Bureau.*)

FIG. 54.—Stratus clouds. (*Courtesy of U.S. Weather Bureau.*)

when convection is exceedingly well developed, the cumulus clouds may extend to great heights and develop into thunderheads. These overgrown cumulus, or *cumulo-nimbus*, clouds are the sources of many local thunderstorms and a considerable part of the earth's rainfall (Fig. 52).

Cirrus. These also are fair-weather clouds, although not infrequently they may be forerunners of an approaching storm. They occur at great altitudes (5 to 9 miles) where temperatures are usually well below freezing so that they are composed of

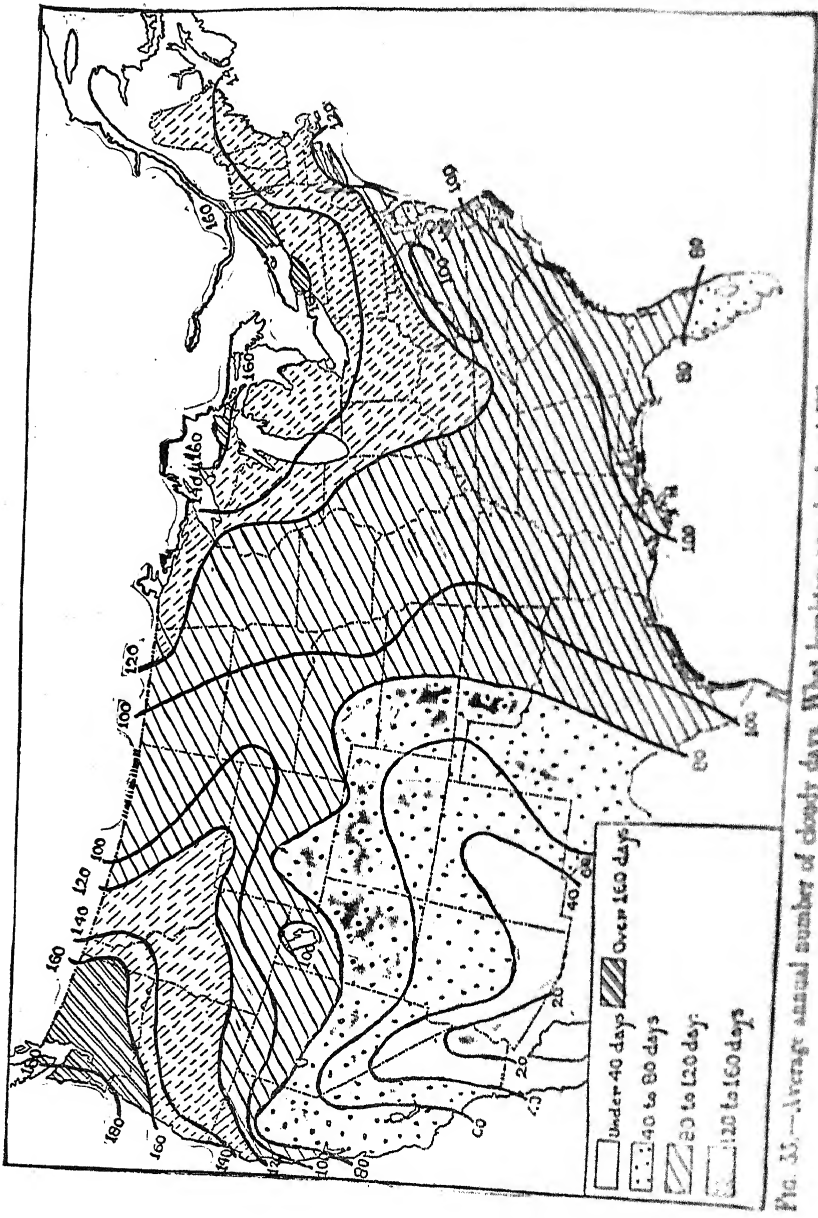


Fig. 35.—Average annual number of cloudy days. What localities are cloudiest? Where would you go if you were looking for a maximum amount of sunshine?

minute ice crystals. Cirrus clouds assume various forms, sometimes appearing like white ringlets, curls, or wisps of hair (Fig. 53). At other times they seem to form an unbroken thin veil of fibrous texture over the whole sky. In the latter case they produce halos around the moon or sun. Never are they thick enough to produce shadows, so they always appear white.

Stràtus. These low-lying layers, or sheets, of cloud form a dull, gray sky of uniform color (Fig. 54). Often the gray ceiling stretches unbroken from horizon to horizon. They are relatively common in winter, producing gray, depressing days. A common method of their origin is mixture along the contact plane between two masses of air of different temperatures. These clouds sometimes bring the ceiling (altitude of bottom side of cloud layer) for airplanes to within 100 or 200 feet of the earth's surface; and since they often cover such great areas, they are a serious hindrance to commercial aviation (Fig. 55).

Nimbus. Thick, dark masses of cloud from which rain is falling are called *nimbus*. The word "nimbus" is usually used in combination with another, such as cumulo-nimbus.

The prefix *alto-* before any of the foregoing names of clouds means *higher than usual. Fracto-* means *broken up.* Thus a rather common cloud type is the fracto-cumulus.

Forms of Precipitation

Rain, Snow, and Sleet. The commonest form of precipitation is *rain*. As stated previously, it is the result of exaggerated condensation in rising air currents, at temperatures above 32°, whereas *snow* forms at temperatures below freezing. *Sleet* is frozen rain and results when raindrops from a warmer air mass above fall through a cold surface layer of air. It is characteristic of the cooler seasons.

Glaze. The accumulation of a coating of ice on objects near the earth, often called *glaze*, is really not a form of precipitation. Fortunately it is not of common occurrence, for the so-called *ice storm* that produces glaze is one of the most destructive of the cool-season types of weather. It occurs when rain, near the freezing point, strikes surface objects whose temperatures are below 32° and is immediately converted into ice. So great may become the weight of the ice accumulation

that trees are often wrecked and telephone, telegraph, and electric wires broken and their posts snapped off (Fig. 56). Such a coating of ice on an airplane may make a forced landing necessary. Most commercial airplanes used for winter flying are equipped with "de-icers," especially on the leading edge of the wing. To prevent a coating of ice from forming on the propeller, a thin spray of oil is thrown on the blades while in flight.

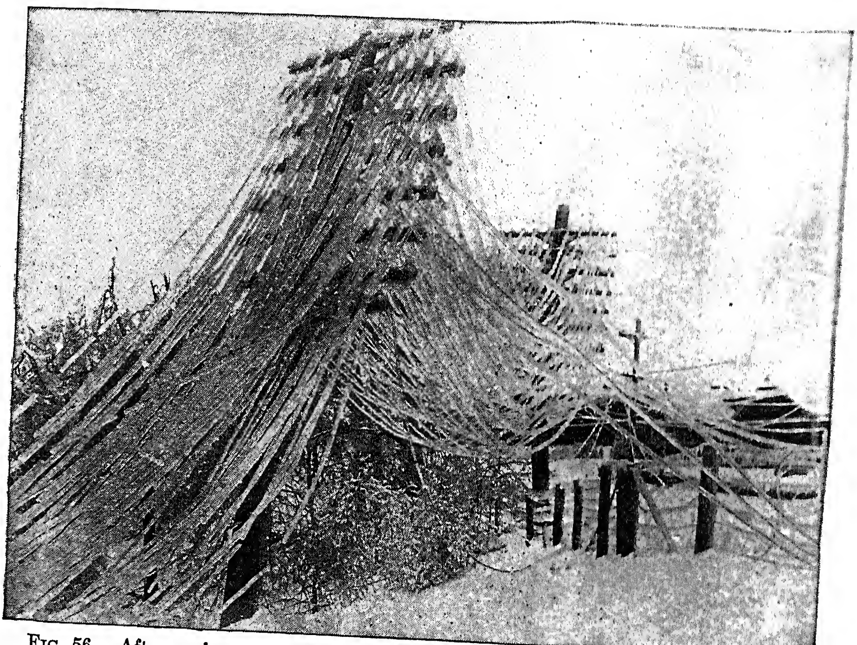


Fig. 56.—After an ice storm. The ice on these telephone wires weighed 800 pounds per wire between poles and was 3 inches in diameter. (*Courtesy of U.S. Weather Bureau.*)

Hail. The heaviest and largest unit of precipitation existing in solid form is *hail*. It is exclusively the product of vigorous convection, occurring in thunderstorms, which in turn usually belong to the warm season. Hailstones are composed of concentric layers or shells of clear ice and of partially melted and refrozen snow, representing the successive vertical descents and ascents in the tumultuous convectional currents of a thunderstorm.

Convectional Precipitation. As a result of the heating of surface air, it expands and is forced to rise by the cooler, heavier

air above and around it. Ordinarily such rising air, since it cools at nearly double the rate of the normal vertical temperature decrease, will rise only a few thousand feet before its temperature has been reduced to the point where it is the same as that of the surrounding air. At that point where the rising air reaches air strata of its own temperature and density, further ascent ceases. But if abundant condensation begins before this stage is reached, then heat of condensation is released, so that with this added source of energy the rising air will be forced to ascend much higher before reaching atmospheric strata of its own temperature. Thus on a hot, humid summer afternoon, when surface heating is intense and condensation abundant, the towering cumulo-nimbus clouds resulting from convectional ascent may be several miles in vertical depth, and precipitation from them may be copious.

Convectional ascent is usually associated with the warm season of the year and the warm hours of the day. Since it is essentially a vertical movement of warm, humid air, cooling is rapid, and the rainfall resulting is likely to be in the form of heavy showers. Because a cumulo-nimbus cloud usually covers only a relatively small area, it quickly drifts by, so that the associated shower is not of long duration. Such "dash" rains are "spotty" and are entirely unlike the general rains over large areas produced by cool-weather lows, or cyclones. Convectional rain, because it comes in the form of heavy showers, is less effective for crop growth, since much of it instead of entering the soil runs off in the form of surface drainage. This is a genuine menace to plowed fields. Soil removal through slope wash and gullying is likely to be serious. On the other hand, for the middle and higher latitudes, convectional rain, since it occurs in the warm season of the year when vegetation is active and crops are growing, comes at the most strategic time. Moreover, it provides the maximum rainfall with the minimum amount of cloudiness.

Orographic Precipitation. Air also may be forced to rise when landform barriers, such as mountain ranges, plateau escarpments, or even high hills, lie athwart the paths of winds. Since water vapor is largely confined to the lower layers of atmosphere and rapidly decreases in amount upward, heavy

orographic rainfall is the result of such forced ascent of air, associated with the blocking effect of landform obstacles. Witness, for example, the abundant precipitation along the western, or windward, flanks of the Cascade Mountains in Washington and Oregon, along parts of the precipitous east coast of Brazil which lies in the southeast trades, or along the abrupt west coast of India which the summer monsoon meets at practically right angles. The leeward sides of such mountain barriers, where the air is descending and warming, are characteristically drier. This arid to semiarid side of a mountain range is called the *rain shadow*.

The most ideal condition for producing heavy orographic rainfall is a high and relatively continuous mountain barrier lying close to a coast, and the winds from off a warm ocean

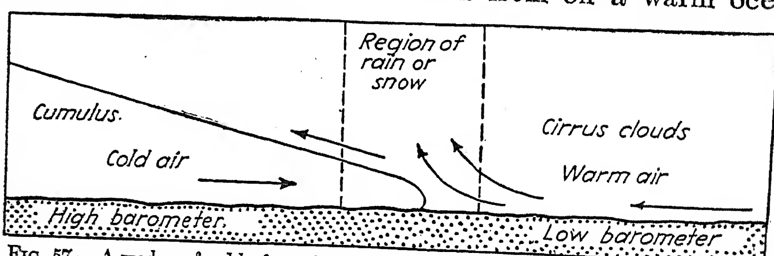
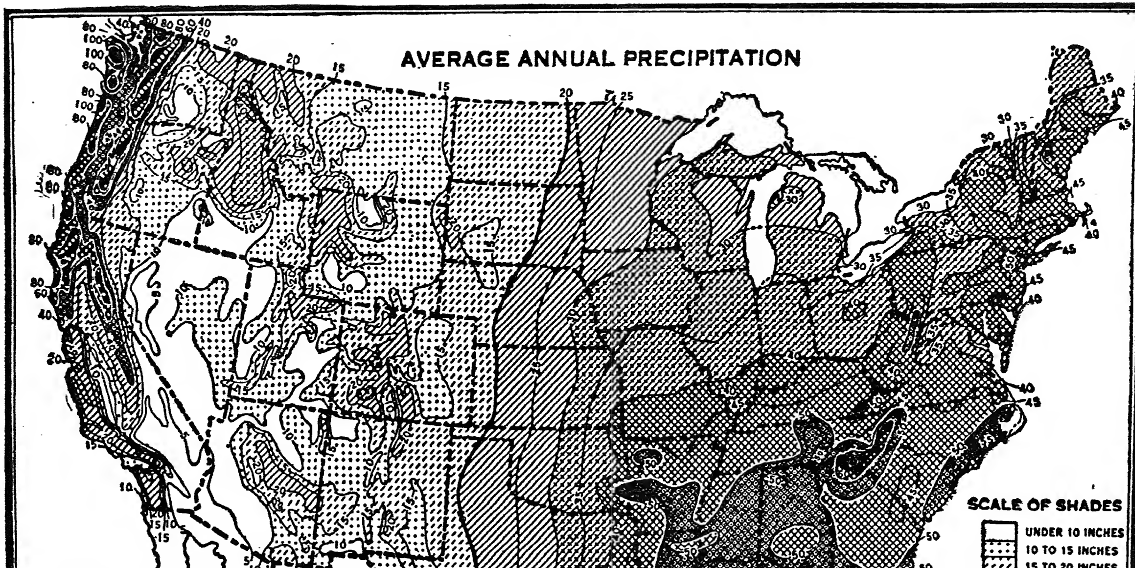


FIG. 57.—A wedge of cold air undermining and uplifting a mass of warm air. Sometimes the lifting is very rapid, causing thunderstorms. At other times it is slow, causing layers of stratus clouds to develop.

meet the barrier at right angles. Orographic rains have less seasonal and daily periodicity than do those of convectional origin. In monsoon regions, very naturally, the maximum is at the time when air is moving from sea to land, usually high sun, or summer. In other regions the strength of the winds, the angle at which they meet the mountain barrier, or the contrast between land and water temperatures may determine the season of maximum orographic rainfall.

Cyclonic Precipitation. In low-pressure storms (cyclones), winds from various directions, and consequently of different temperatures and densities, tend to come together about a center of low barometric pressure (see following chapter). As a result of such movement, great volumes of air are lifted and cooled. When a warm tropical air mass moves toward a colder polar air mass, the warmer, lighter air will be lifted by the



AMOUNT OF PRECIPITATION	LAND AREA, ACREAGE	PER CENT OF TOTAL LAND AREA OF U. S.
Under 10 inches	153,634,432	8.1
10 to 20 inches	588,775,719	30.9
20 to 30 inches	314,258,301	16.5
30 to 40 inches	320,089,545	16.8
40 to 50 inches	324,846,189	17.1
50 to 60 inches	160,366,829	8.4
60 to 80 inches	28,898,105	1.5
80 to 100 inches	9,430,528	0.5
Over 100 inches	2,915,712	0.2

FIG. 58.—Average annual rainfall. (*Reduced and generalized from map prepared by U.S. Weather Bureau for Atlas of American Agriculture.*)

cooler, heavier air. Unlike convectional ascent, which involves direct vertical lifting, the warmer air in cyclones more often rises obliquely and therefore slowly, along mildly inclined surfaces of cold, dense air, and cooling as a consequence is less rapid (Fig. 57). As a result of the slower ascent and cooling, precipitation in cyclones is characteristically less violent than in thunderstorms and is inclined to be steadier and longer continued.

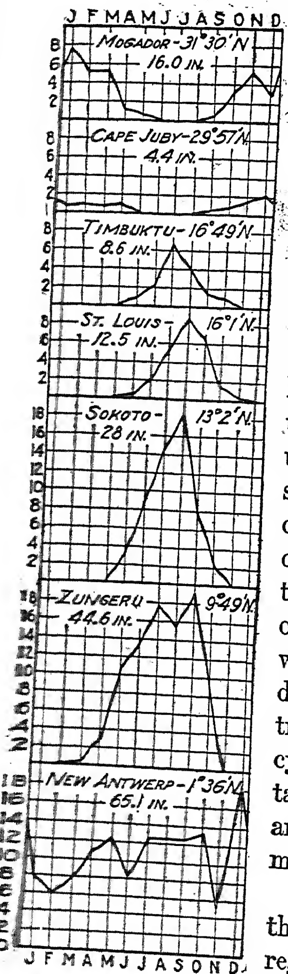


Fig. 59.—These rainfall charts for seven stations in Africa north of the equator illustrate rainfall regimes in low latitudes. Stations are arranged according to latitude with Nouvelle Anvers (New Antwerp) closest to the equator.

The dull, gray, overcast skies and drizzly precipitation of the cooler months in middle latitudes, producing some of the most unpleasant weather of those seasons, are usually associated with cyclones. These storms are most numerous and best developed during the cool season. Where they dominate weather conditions, therefore, they tend to produce more rain in autumn or winter than in summer. Most of the winter precipitation of lowlands in the middle latitudes is cyclonic in origin. In the tropics, as well as in the middle latitudes, cyclones are important generators of precipitation, although the storms of low latitudes are of a different origin and their rainfall may be likewise.

Important Precipitation Data. At least three items concerning precipitation of a region are of outstanding importance: (1) its total average amount or depth for the year (Fig. 58); (2) its seasonal distribution (Fig. 59); and (3) its dependability, both annual and seasonal.

The total annual amount of rain is important, and seasonal distribution is equally so. Omaha, Neb., receives 30 inches of rainfall annually. During the months from May to August inclusive the rainfall is 17.4 inches (57 per cent),

and only 3.3 inches (11 per cent) during the period November to February inclusive. The fact that the majority of the precipitation occurs during the growing (warm) months is extremely important from the standpoint of the production of economic crops. Variability in the total amount of precipitation from year to year (its dependability) is hardly of less importance, especially for regions that are normally subhumid. It is a general rule that variability increases as the amount of rainfall decreases.

The average annual amount of rainfall and its characteristic seasonal distribution at any place (rainfall regime) depend upon (1) accessibility to moisture-bearing winds, usually from the ocean, and (2) the existence of conditions, principally storms, favorable for the condensation of water vapor. Both conditions are essential. The accessibility of a region to moisture-bearing winds is related to (1) the general distribution of pressure and winds, (2) the character of relief features on the land surface, and (3) the distance from oceans, the principal source of water vapor for the lands. The distribution of rainfall over the continents is discussed more fully in the chapters dealing with climate.

Summary

The ratio of absolute humidity to capacity, expressed in percentage, is called relative humidity. When air is warmed, its capacity to hold water vapor increases. On the other hand, if air is cooled below the dew point, water vapor condenses into such forms as clouds, fog, dew, and frost. The lifting of great masses of air causes condensation of water vapor on a large scale. This in turn brings about the precipitation so necessary to the growth of vegetation. Based on origin, there are three types of precipitation: convectional, orographic, and cyclonic. Annual rainfall and seasonal distribution are extremely important factors in the production of economic crops.

In the last three chapters we have studied the temperature, pressure, and moisture of the atmosphere. All these are involved in great disturbances of the air, which go by the general name of storms. Our next chapter deals with the subject of storms, the paths that they follow, and the changes in weather that they bring.

Questions

1. State four ways in which water vapor in the air is of considerable importance.
2. What is the primary source of water vapor in the air?
3. What is evaporation? What factors determine the rate of evaporation?
4. What is condensation? Is it caused by heating or cooling of the air?
5. At what temperature does air condense into liquid air?
6. What is the nature of air that causes ice to form on airplanes in flight?
7. What is a calorie? How many calories are required to change 1 gram of ice into water at 32°? To change water into water vapor at the same temperature?
8. What is one reason why water bodies heat slowly?
9. What is meant by latent heat of condensation? How does it affect the intensity of a storm? Why?
10. What is capacity? Saturated air? Which is heavier, air or water vapor?
11. What is absolute humidity? Which ordinarily has greater A.H a tropical or a polar air mass? Why?
12. Why are absolute and relative humidity often very low during dust storms?
13. On the average, when would you expect R.H. to be lower, at noon or at midnight? Why?
14. What is meant by relative humidity? If A.H. remains the same, what happens to R. H. when temperature increases? Decreases?
15. What is dew point? What is the dew point of air at 70° that has an A.H. of 4.1 grains per cubic foot?
16. How much water vapor is condensed when 100 cubic feet of saturated air is cooled from 80° to 40°?
17. Air at 100° has a R.H. of 10 per cent. What is A.H.? The dew point?
18. Air at 80° has a R.H. of 50 per cent. What is the dew point?
19. Certain air at 90° has A.H. of 3.35. What is R.H.?
20. If $AH = 2$ and $RH = 25$ per cent, what is C? What is the temperature?
21. Outdoor air at 40° with R.H. of 70 per cent is brought indoors and heated to 70° with no water vapor added. What is R.H. indoors?
22. A theater brings indoors 100,000 cubic feet of air at 90° with R.H. of 80 per cent. This air is cooled to 70° with R.H. of 50 per cent. How much water is condensed? (7,000 grains = 1 pound)

23. Why is dry air indoors in winter possibly detrimental to health?

24. How can moisture be added to air indoors in winter?

25. Why do we feel uncomfortable on hot, humid days?

26. What is air conditioning? What processes are involved?

27. Which has a lower dew point, moist or dry air? Why?

28. Why is dew (or frost) more likely to form on clear, calm nights than on cloudy, windy nights?

29. Why do we often see "lakes" of fog in low places?

30. What causes the darkness and persistence of London fogs?

31. What is dew? Why does it form quickly on grass?

32. What is frost? Is most frost frozen dew?

33. Differentiate between radiation and advection fogs.

34. What causes the dense fogs in our Central states in winter? On the coast of California? Around Newfoundland?

35. What is the rate of cooling of rising air currents?

36. When air descends, what happens to its temperature? Why?

37. What is the principal cause of abundant precipitation?

38. What is a cloud?

39. Clouds and fog differ in what respect?

40. Precipitation has its origin in clouds as a result of what process?

41. What are the colors of the solar spectrum as shown by a rainbow?

42. What causes a rainbow? A halo of the moon? The colors of sunrise and sunset?

43. What are the four principal types of clouds? Describe each.

44. Which cloud type is the source of a thunderstorm?

45. Which is the highest cloud type? The lowest?

46. Why are stratus clouds a hindrance to aviation, probably more than any other type?

47. What is meant by the cloud prefix alto-? Fracto-?

48. What is sleet? Glaze? Hail?

49. Explain the cause of convectional rain. What are some objections to this type of rain?

50. Explain the cause of orographic rain. Mention a few exact locations where such rain occurs.

51. What is a rain shadow? Give an example.

52. What are the ideal conditions that produce heavy orographic rain?

53. Explain the cause of cyclonic precipitation. Why is it usually less violent than convectional?

54. What precipitation data are important?
55. What two factors determine the rainfall regime of a region?

Suggested Activities

1. Using the wet-and-dry bulb method, test relative humidity of the air every hour of the day, outdoors and indoors. Plot curves to show results. Repeat during the various seasons of the year.

2. Observe a hygrograph, if one is available. It records relative humidity on graph paper. Most of them operate for a week at a time. The hygrograph curve shows clearly the change in relative humidity during day and night and the difference in moisture content of the air during rainy spells and dry weather.

3. Determine the dew point of air, indoors and outdoors. Explain the difference, if any.

4. If possible, visit a weather bureau, and observe the instruments for measuring and recording rain and snow. Note also the care with which all data are recorded.

5. If possible, visit an airport. Make inquiry concerning ice formation on airplanes and methods of prevention.

6. Using a triangular glass prism, observe the colors of the solar spectrum. Note these colors also in a rainbow, when visible.

7. Study the operation of a hair hygrometer, if one is available.

8. Construct or purchase a rain gauge. Send to U.S. Weather Bureau, Washington, D.C., for bulletin on meteorological instruments. Secure catalogues from manufacturers, giving descriptions and prices of instruments.

9. Keep a daily record of cloud types and rainfall.

10. Using climatic data available, plot relative humidity and rainfall curves for selected places.

Note: Other activities may be found in the laboratory manual.

Topics for Class Reports

1. Air Conditioning
2. Methods of Testing Air for Relative Humidity
3. Variation in Relative Humidity over the United States
4. Clouds and Their Meaning
5. Measuring Rain and Snow
6. Methods of Determining the Dew Point
7. Variations in Annual Rainfall in Your Home Community during the Past 20 Years
8. The Quantity of Rain Needed for Certain Economic Crops
9. Examples of Orographic Rain and Rain Shadow

10. Contrasting Rainfall Distribution over North and South America

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Chapter V. Storms and Their Weather Types

The coming and going of a big thunderstorm is often a fascinating sight. If we were to take note of the storm's behavior, we should find that the sequence of events is about as follows:

On a quiet, hot, humid morning fleecy cirrus clouds are visible in the sky. The barometer shows a slight, steady drop. There is a high degree of humidity, and gradually the heat becomes more intense. The rapid rising of the warm, moist air causes great cumulus clouds to appear in the west. As these clouds approach, they darken to cumulo-nimbus and are churned and tossed about by high winds. A flash of lightning produces a loud clap of thunder. Suddenly, a brisk, cool breeze starts blowing. This cool air causes the barometer to rise quickly.

Now huge clouds obscure the sun. There are vivid flashes of lightning, followed by peals of thunder. An enormous amount of energy is being released in the atmosphere. Rain is falling in great sheets, and for a few minutes small hailstones patter against the window. The downpour continues for perhaps an hour. During this time the lightning and thunder become less and less frequent. Finally the sky clears in the west, as the storm retreats toward the east. A cool breeze begins blowing from the northwest, and the drop in temperature is noticeable. We look at the barograph and notice that the passing of the storm has produced a jagged appearance in the pressure curve traced by this instrument.

Such storms as the one just described occur during the warm months over much of the United States. In connection with the preceding description, certain things that we have learned should be recalled.

1. Convection currents produce cumulus clouds.

2. Condensation within the storm liberates latent, or stored-up, heat, increasing the strength of rising air currents and the intensity of the storm.

3. The coming and going of the storm cause changes in wind direction and air pressure.

The torrential rain may cause considerable soil wash, but the moisture is welcomed by growing crops. It is well to remember that storms are the earth's principal generators of precipitation. Without them, the great lowlands of the earth would be far less habitable than under existing conditions.

The present chapter deals with storms. It is concerned mainly with (1) the nonviolent cyclones and anticyclones of the middle latitudes, or intermediate zones; and to a lesser extent with (2) thunderstorms; (3) tornadoes; and (4) tropical storms.

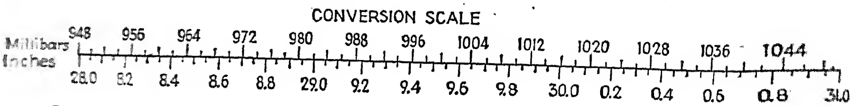
Middle-latitude Cyclones and Anticyclones

Nature and Location. As we have already said, cyclones are characterized by low barometric pressure and commonly go by the name of *lows*. Anticyclones are characterized by high pressure and are called *highs*. The cyclone, therefore, must consist largely of a mass of relatively light air, and the anticyclone of heavier air. This difference in weight, or pressure, is not noticeable except by watching the changes in a barometer or barograph. A low barometer indicates cyclonic; a high barometer, anticyclonic weather. Since these disturbances occur within the belt of westerly winds, they are best known in those latitudes between parallels 35 and 65 in both Northern and Southern hemispheres. Cyclones and anticyclones are *not violent* atmospheric disturbances as are tornadoes and hurricanes.

Appearance and Pressure. On the daily weather map, these storms are shown by a number of V-shaped or circular isobars drawn around a point of low pressure. In the center of the cyclone the word *low* indicates the region of lowest pressure. From the center toward the margins the pressure *increases*. In the center of an anticyclone the word *high* indicates the region of highest pressure. From the center toward the margins, the pressure *decreases*.

Average barometric pressure at sea level is about 30 inches, or 1,015 millibars. The millibar is a term used in the metric

system and is applied to a very tiny amount of force. In round numbers, $\frac{1}{10}$ inch on a barometer or barograph is equivalent to about 3 millibars. Either inches or millibars may be used in numbering the isobars on a weather map. The relation of millibars to inches is shown by the following scale:



On the weather map all pressure readings are reduced to sea level by adding approximately 1 inch for each 900 feet above sea level. At a place 4,500 feet above sea level, about 5 inches would be added to the local barometer reading in transferring the pressure to the weather map. The isobars are drawn for each tenth of an inch of pressure. In the autumn, winter, and spring,

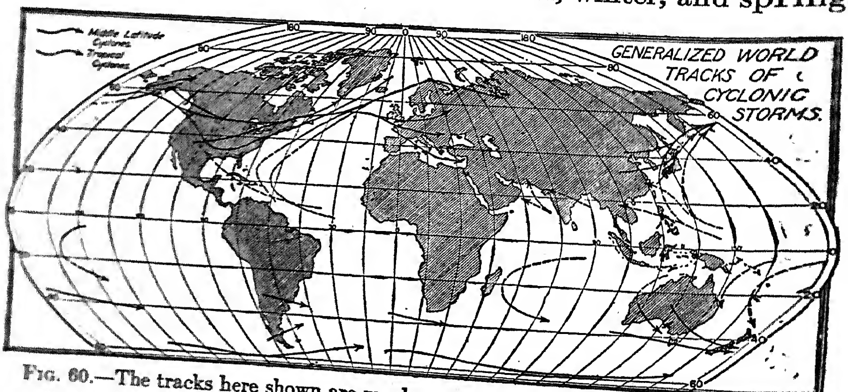


FIG. 60.—The tracks here shown are much generalized. (*Modified from Knight.*)

the pressure in the center of a cyclone may be $\frac{1}{2}$ inch or more below normal (30 inches); and in the center of an anticyclone, $\frac{1}{2}$ inch or more above normal. In well-developed storms the difference in pressure between the high and low may be more than 1 inch. A general rule is that both cyclones and anti-cyclones are less well developed, have smaller differences in pressure and weaker pressure gradients, and travel at slower speeds in summer than in winter. Cyclones are extensive rather than intensive storms. In some cases they are 1,000 miles or more in diameter. In cyclones with V-shaped isobars, the north-south distance across the storm frequently is greater than the east-west.

Direction and Rate of Movement. Lows and highs travel in general toward the east, carried along by the upper air system of westerly winds in which they exist. This is not to say, however, that they always travel due east. Certain paths are followed more frequently than others (Fig. 60). It is evident that in forecasting weather one should observe storm developments to the west and not to the east of a given place. Those storms to the east have already gone by; those to the west are approaching.

Lows and highs sometimes vary considerably in the speed at which they move across the country. Changes in speed and direction may account for failure in forecasting. In the United States, lows move across the country at an average speed of 20 miles per hour in summer and 30 miles per hour in winter. Highs usually move more slowly than lows. In summer, the intensity of highs and lows is greatly reduced. As a consequence, warm-season weather is less changeable, and atmospheric disturbances are less violent. In winter, a well-developed low usually crosses the United States in 3 to 5 days.

Wind Systems in Cyclones and Anticyclones

Wind System in Cyclones. Air flows from high to low pressure. Since the lowest pressure is in the center of a cyclone, it is evident that winds will blow toward that center. As air masses of contrasting origins, temperature, and humidity move toward the center of a low, the warmer and more humid air is lifted, sliding upward over cooler or drier air. This lifting of humid air usually results in the formation of clouds from which rain or snow may fall.

Surface winds blow in a general way toward the center of a low. On the east side, or front, of the storm, the winds blow mainly from easterly points. On the west side, or rear, of the storm the wind directions are westerly. Southeast and south winds prevail in the southeast quadrant (Fig. 61). These winds in central or eastern United States are likely to be mild and humid, since they may come from the Gulf of Mexico or the Atlantic Ocean. They are thus valuable importers of much needed moisture. Northwest wind prevails in the northwest quadrant of the storm. This wind often comes from western or central Canada and is cooler and drier than the southeast and

south winds. In winter, the northerly winds often are bitterly cold. The cyclone, then, is a meeting place of contrasting air masses. Thus a mild, humid air mass arrives from warmer latitudes on the front and equatorward sides of the storm. A colder, drier, and heavier air mass arrives from higher latitudes on the rear and poleward sides.

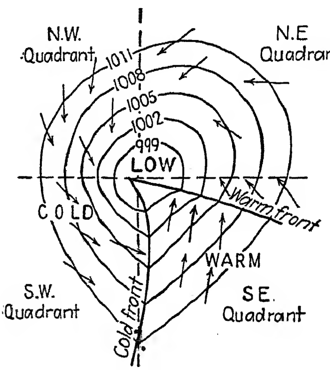


FIG. 61.—A cyclone, or low, as it often appears on the weather map. Arrows fly with the wind. Note that south and southeast winds prevail in the southeast quadrant, northwest winds in the northwest quadrant, and east-northeast winds in the northeast quadrant. The advancing cold front, which causes a wind shift from south to northwest is shown in the southeast quadrant. It is along the cold front that squalls, rain, snow, and sometimes severe thunderstorms are likely to occur.

Wind Shift with the Passing of a Cyclone. Although the center of a cyclone is west of an observer, he will experience general easterly winds. As the center passes and the observer finds himself in the west side, or rear, of the cyclone, he will note mainly northwest or west winds. Easterly surface winds, therefore, often indicate the approach of a cyclone with its accompanying clouds and rain. Westerly surface winds more often foretell the retreat of the storm center toward the east and the coming of clearing weather as an anticyclone moves in from a westerly direction.

In most storms the shift from easterly to westerly winds is rather gradual. In some, however, the wind shift is very abrupt. Especially is this true where isobars south of the storm center tend to take the form of a letter V pointing toward the south or southwest (Fig. 62). In such a low an irregular line extending

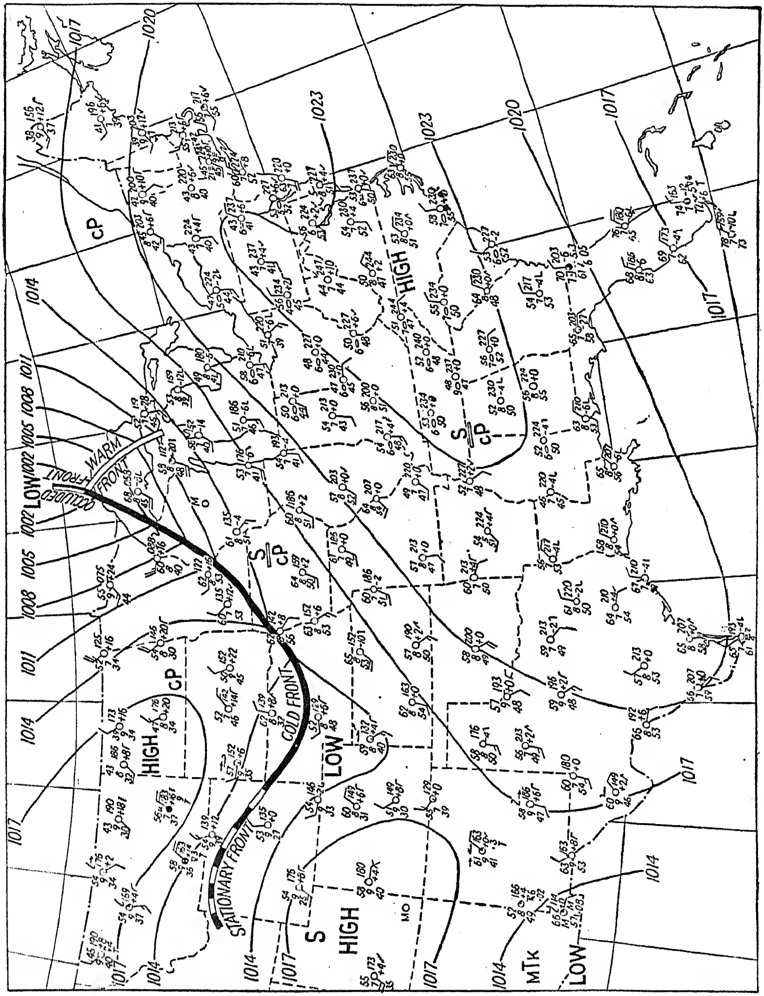


FIG. 62.—Daily weather map.

usually from the center toward the southwest is called the *wind-shift line.* Along this line, the wind is in the process of shifting from southerly to northerly points. The wind-shift line is also known as the *surface cold front,* since it marks the front edge of the cool or cold polar-air mass which is advancing toward the south and east. This cold-air mass, being relatively denser, undermines and forces upward the warmer and more humid air masses that it encounters. Along the wind-shift line of such a cyclone, therefore, violent atmospheric disturbances may occur. These often include a sharp drop in temperature as the wind suddenly changes from southeast to northwest, accompanied by rain or snow and, in warm seasons, thunderstorms.

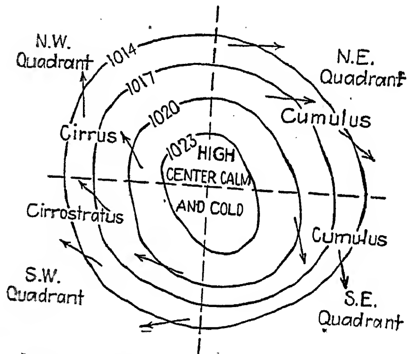


FIG. 63.—An anticyclone, or high, as it often appears on the weather map. Note the prevailing wind direction and cloud type in each of the four quadrants. Arrows fly with the wind.

The cold front is the boundary between two masses of air having different characteristics with respect to temperature and humidity. Ahead, or to the east, of the front is found relatively warm air of high water vapor content; behind, or to the west of, the cold front the air is usually noticed to be of lower temperature and less moisture. Along the front iself there is a reaction between the two masses of air of different density values. This reaction often results in weather types which pilots are particularly interested in knowing about. Such phenomena as extremely bumpy air, showers, thunderstorms, poor visibility and low ceiling are common, and pilots need all the information which is available concerning cold fronts in areas where flights are contemplated. Fortunately cold fronts are easy to identify on

weather maps, and their rates and direction of movement can be forecast more certainly than some other weather types.

Wind System of an Anticyclone. Surface winds blow out from the center of an anticyclone, or high (Fig. 63). Cooler, heavier air evidently settles to the earth at the center. To the east of the center, therefore, winds blow in general from westerly directions. To the west of the center they blow from easterly directions. The center of an anticyclone often brings relatively calm and fair weather.

Cyclones and anticyclones follow one another in a sort of parade across the United States, resulting in many and varied changes in weather. The northwest wind to the south and east of a high that is centered in western Canada may bring a severe cold wave or blizzard to central and eastern United States. At such times the cold polar-air mass may move as far south as the Gulf states, causing considerable suffering among people and livestock.

Precipitation in Cyclones and Anticyclones. In general, cyclones bring unsettled weather with rain or snow, and anticyclones bring fair or partly cloudy weather. Precipitation is more likely to occur in the cyclone, because it is a region where unlike air masses comes together. The warmer and more humid air masses are lifted by the colder and denser ones so that cooling and condensation of water vapor are likely to result. Not every cyclone is accompanied by precipitation, because (1) absolute humidity of the air may be too low and (2) there may not be sufficient lifting of the air to cause it to reach the condensation level. In the anticyclone, air at the center is slowly settling from higher altitudes. As it settles, it becomes warmer, its capacity for moisture increases, and little precipitation results.

Precipitation over the lowlands of the United States in the cool months is largely cyclonic in origin. In the summer months the heat increases the strength of rising air currents, and convectional rainfall results. Thunderstorms bring heavy "dash" rains of short duration. Cyclonic rainfall, on the other hand, tends to be light and steady, lasting for hours, sometimes days, and often covering considerable areas. This is due to the *slow* lifting of warm, humid air masses by underrunning cooler air (Fig. 57). Such lifting is much less rapid than that caused by

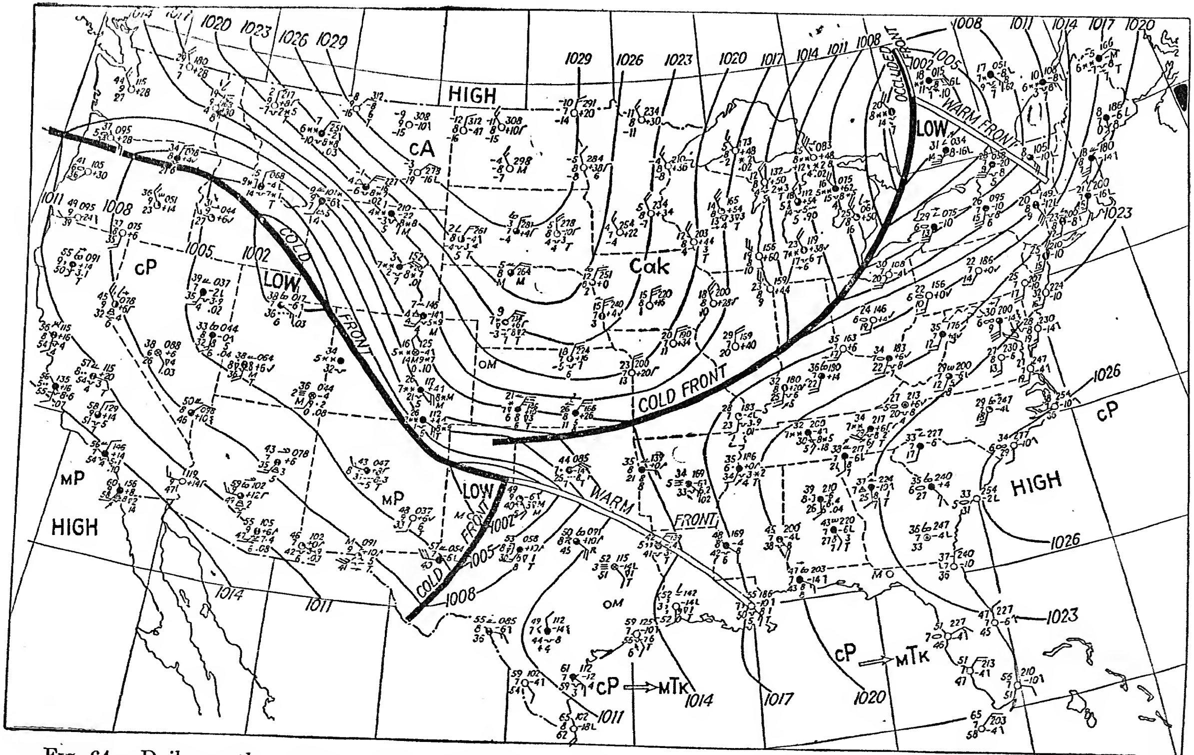


Fig. 64.—Daily weather map. The large anticyclone, or high, was caused by a Continental Arctic (*cA*) air mass which moved southeastward from the arctic region to the Gulf of Mexico. Notice the cold temperatures in the northern plains states where the air mass is moving into the United States. This map is typical of those of the early part of winter; later in the winter season even colder temperatures occur. Note that isobars are numbered in millibars. Three millibars is equivalent to about $\frac{1}{10}$ inch on the mercurial barometer.

strong convection currents in thunderstorms. The steady cyclonic rain is beneficial in that much of it seeps into the ground. On the other hand, a considerable part of thunderstorm down-

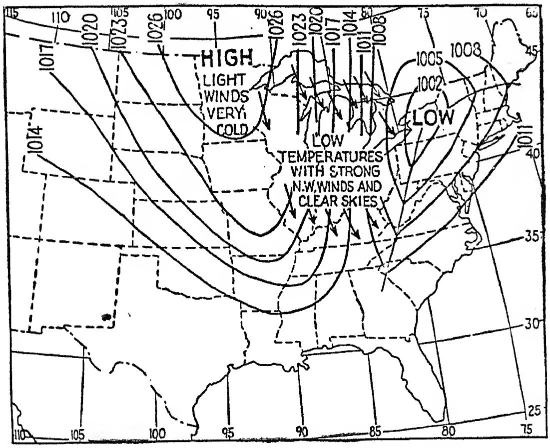


FIG. 65.—A winter anticyclone advancing southeastward as a mass of Cold Polar Continental air.

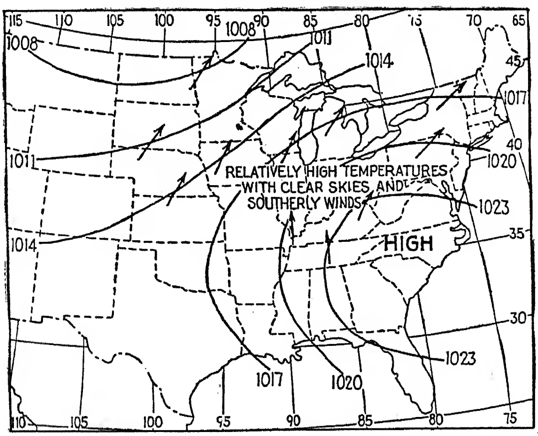


FIG. 66.—A relatively stagnant anticyclone over southeastern United States producing unseasonably warm weather over the central and eastern parts of the country.

pour disappears by rapid surface runoff. Especially in freshly plowed fields, this causes disastrous soil erosion.

Temperatures in Anticyclones. In winter a well-developed high advances toward the east and southeast. It is a mass of Polar Continental air from northern and western Canada. Its temperature is so low that it brings a cold wave to central and eastern United States (Figs. 64 and 65). In such highs the

temperature ranges from zero to 20° or 30° below. If accompanied by high winds and snow, a blizzard is the result. For example, the weather map in Fig. 64 shows a high over the Northern Plains states. The cold weather produced at this time resulted in temperature readings well below the normal. In summer a similar high brings a few days of relatively cool delightful weather. It is relatively easy to forecast.

Occasionally in summer a high develops over the Southern states, and a slow-moving low travels along the Canadian border (Fig. 66). A hot wave results from the hot, dry south and southeast winds that blow for several days from the high to the low. Prolonged periods of such dry weather are called *droughts*. At such times evaporation of moisture from soil and growing crops is tremendous. Pastures dry up, and corn "fires," meaning that the lower portions of the corn plant turn to a yellowish-brown color.

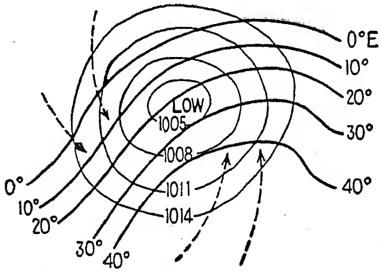


FIG. 67.—Characteristic arrangement of isotherms in a winter cyclone over central and eastern United States. The front half is usually warmer than the rear half.

Temperatures in Cyclones. Severe contrasts in temperature often occur within a cyclone area. In the southeast quadrant of a low the temperature is usually relatively high as the result of southeast and south winds. In the northwest quadrant, lower temperatures are due to northwest winds. The front, or east half, of the cyclone is generally a region of higher temperatures than the rear, or west half (Figs. 62, 67). This is because the southerly winds import warmth from lower latitudes. In winter, in central and eastern United States, the temperature in the southeast quadrant of a low may be 50°; in the northwest quadrant it may be down to zero or below.

As the storm center passes, a sudden drop in temperature of some 40° or 50° may occur. The warm air of the southeast quadrant is usually humid. In summer it produces "sticky, muggy weather." In the northeast quadrant, where northeast winds often prevail, temperatures are usually lower than in the southeast quadrant. In winter the drop in temperature caused by the advancing cold front may cause rain to change to snow.

Sometimes in the colder months the cloud cover that accompanies a low often results in temperatures above normal. This is because the clouds prevent rapid radiation of heat from the earth at night. A similar cloud cover in summer may produce temperatures below normal, because the clouds tend to weaken incoming solar radiation.

As a low approaches from the west, the warmer, lighter air mass in the southeast quadrant causes the barometer to fall steadily. When the storm center has passed, the cooler or colder denser air mass (northwest or west winds) in the west quadrants causes the barometer to rise (Fig. 68).

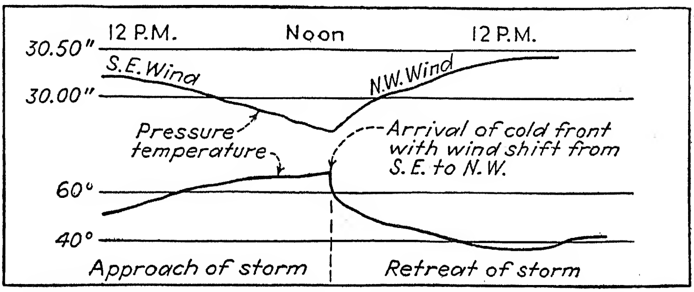


FIG. 68.—Behavior of temperature and pressure during the approach and retreat of a low. As the storm approaches from the west, temperature rises and pressure falls. The arrival of the cold front causes a sharp drop in temperature and a rise in pressure. The temperature curve is made by a thermograph, or self-recording thermometer. The pressure curve is made by a barograph, or self-recording barometer (see Appendix C).

Paths of Cyclonic Storms. Although cyclones do not follow definite tracks around the world, certain paths are frequented more than others. In North America more lows move eastward along the Alberta and North Pacific tracks than along any other two paths (Fig. 69). In the cool seasons lows follow paths farther south, *e.g.*, the South Pacific. Storms that follow this path sometimes bring prolonged rains or heavy snows. Other paths, frequented especially in winter, extend from Texas and Florida northward along the Atlantic Coast.

In Europe, lows follow mainly a path across the British Isles and northern Germany. In winter they sometimes travel farther south, crossing Mediterranean countries.

In the Southern Hemisphere, lows are energetic throughout the year. They travel eastward, following paths located for the most part between the parallels 40°S. and 60°S. The Cape Horn region

of South America, extending as it does to nearly latitude 55°S., is a stormy area at all times of the year.

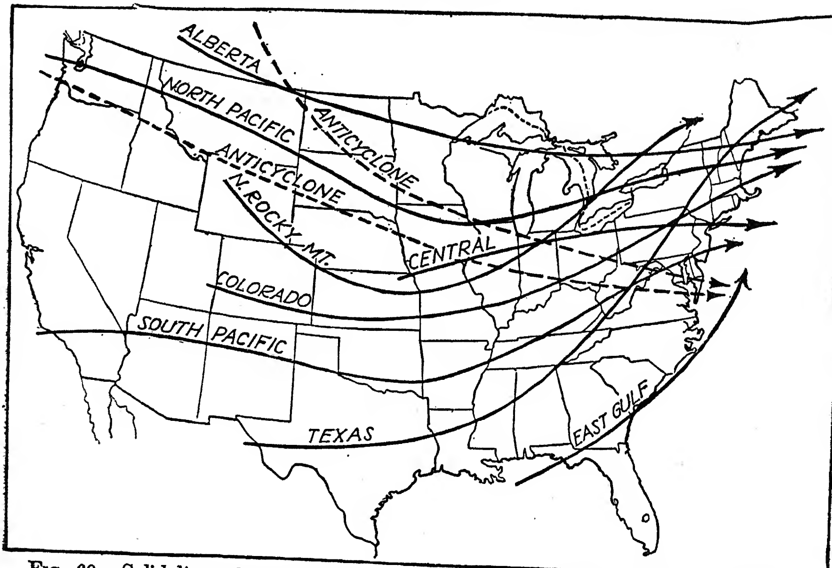


FIG. 69.—Solid lines show principal tracks of cyclones as they cross the United States; broken lines are principal tracks of anticyclones. Anticyclones that move southeast from western Canada sometimes bring extremely cold weather in winter; those from the western states bring moderately cold or cool weather. (*After map by U.S. Weather Bureau.*)

Weather Forecasting

Daily Weather Map. At 1:30 and 7:30 A.M. and P.M., Eastern Standard time, the condition of the weather is recorded at some 300 stations scattered over North America. This information is transmitted by telegraph and teletype to all parts of the United States and much of Canada. Trained men assemble the data on a large map, locate the highs and lows and the warm and cold fronts, draw the isobars, and label the air masses. The result is the completed daily weather map (see Appendix C).

The official forecaster studies this map and tries to picture the changes in positions of storm centers and fronts during the next 24 to 36 hours and the effects that these changes will have on the weather in his own local district. Since weather conditions differ in different localities, it stands to reason that a forecaster's accuracy should increase the longer he is stationed at one city. Regional experience is the best teacher.

Certain rules and types of weather maps should be mentioned with reference to weather forecasting.

1. In general, weather travels eastward.

2. Lows tend to follow certain paths at certain seasons of the year.

3. A low usually crosses the United States in 3 to 5 days.

4. The approach of a low from the west usually foretells unsettled weather; a high, fair or partly cloudy and cooler or colder weather.

5. Lows that follow paths across southern United States in winter are usually more intense and energetic than those which travel east along the Canadian border.

6. As a storm center passes, the temperature will drop, the amount of drop being determined largely by the *contrast* in temperature between the low and the high that lies to the west or northwest.

7. Highs tend to travel from western Canada and the Pacific Coast toward the Central Atlantic states; lows move toward New England.

8. In general, lows travel faster than highs.

9. A high over Montana, the Dakotas, and western Canada with temperatures 20° to 40° below zero may advance toward the southeast, causing a severe "cold wave" to reach sometimes as far south as the Gulf states. Along the advancing cold front of such a high, blizzards may be experienced.

10. A high-pressure area over Nevada, Utah, and Idaho, called a *Great Basin high*, may remain stationary for several days, causing fair weather and westerly winds to prevail over most of the states between the Rocky Mountains and the Mississippi River. Such highs bring moderately cold weather.

11. In summer, a stationary low in central North America, with a high over the Southeastern states may cause a hot wave and drought over much of central and eastern United States.

12. A northeast or east wind, a falling barometer, and a temperature near freezing are good indications of an approaching snowstorm.

13. The *change* in temperature is usually greater when the storm center passes *north* of the observer.

14. In the United States, storms tend to increase in intensity east of the Mississippi River.

15. During the cool months, a high over Minnesota and the Lake Superior region, together with a low in the Southwestern states, often causes cloudy weather with rain or snow over the Central states west of the Mississippi River.

16. The southwest quadrant of a high often tends to be a region of stratus clouds and light, drizzle rains.

17. Violent atmospheric disturbances often develop along the cold front, or wind-shift line.

18. In general, winds from points east, with a falling barometer, indicate foul weather; winds shifting to points west indicate clearing and fair weather.

Suppose that a cyclone is moving eastward across the United States. If the center of the low passes to the north of an observer, so that he is in the southern quadrants of the storm, the succession of winds experienced will be southeast, south, southwest, and finally west and northwest (Fig. 61). This is called a *veering wind shift*. On the other hand, if the storm center passes south of the observer, so that he is on the north side of the cyclone, he will experience in succession northeast, north, and finally northwest winds. This is known as a *backing wind shift.*

The following note regarding wind-barometer indications associated with a passing cyclone appears on the United States daily weather map:

> When the wind sets in from points between south and southeast and the barometer falls steadily, a storm is approaching from the west or northwest, and its center will pass near or north of the observer within 12 to 24 hours with wind shifting to northwest by way of southwest and west. When the wind sets in from points between east and northeast and the barometer falls steadily, a storm is approaching from the south or southwest, and its center will pass near or to the south or east of the observer within 12 to 24 hours with wind shifting to northwest by way of north. The rapidity of the storm's approach and its intensity will be indicated by the rate and the amount of the fall in the barometer.

Air-mass Analysis

Forecasting Aided by Knowledge of Air Masses. Weather men devote a great deal of time to the study of air masses. They

are interested especially in (1) the origin of a given air mass, (2) its characteristics, (3) its rate and direction of movement, and (4) the type of weather that is likely to result where two contrasting air masses come together. The movements of air masses and their effects upon weather have been observed for many years.

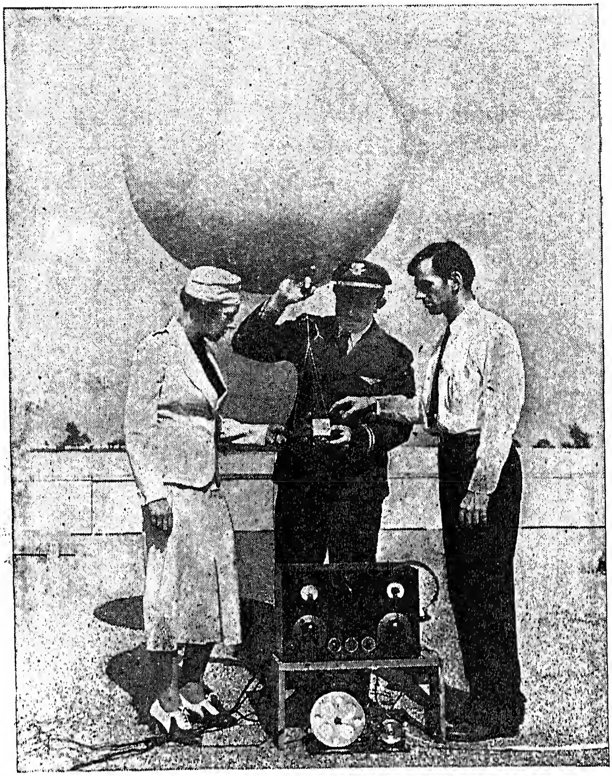


FIG. 70.—A large balloon that carries a radio-meteorograph into the upper atmosphere. This instrument broadcasts temperature, pressure, and humidity. The signals are received by the special radio set shown on the little bench. (*Courtesy of Transcontinental and Western Air, Inc.*)

Today, however, additional data are secured from self-recording instruments carried aloft by airplanes and balloons. These data make possible a more accurate analysis of the air mass. Considerable attention is being given to the development of the *radio-meteorograph* (Fig. 70). This is an instrument which automatically broadcasts by radio upper air data (temperature, pressure, humidity) when it is carried upward by a balloon. The term *radiosonde* is applied to such data.

Wind velocity and direction aloft are ascertained by releasing pilot balloons. These are rubber and about 2 feet in diameter, filled with hydrogen. They are released several times a day, and their movements are observed through a telescopic instrument called a *theodolite* (Fig. 71). The balloon rises a certain number of

FIG. 71.—A weather observer about to release a balloon which will be watched through the theodolite shown. Such observations make possible the determination of wind direction and velocity at high elevations. (*Courtesy of American Airlines, Inc.*)

feet per minute. If it goes out of sight in the clouds, the time elapsed is noted. The time interval is changed to feet. This gives the altitude of the bottom side of the clouds, which is called the cloud *ceiling*.

All this means that a more intensive study is being made of the vertical structure of the atmosphere. By using radiosonde and pilot-balloon data, meteorologists make upper-air charts that show temperature gradients, moisture content of the air,

and the direction of winds aloft. These are called *isentropic charts.* The upper-air data also are plotted on special graph paper. This helps the meteorologist in his analysis of air masses and in determining weather changes that may take place within the next day or so. These studies are a step forward in the development of weather science and are contributing to greater accuracy in forecasting.

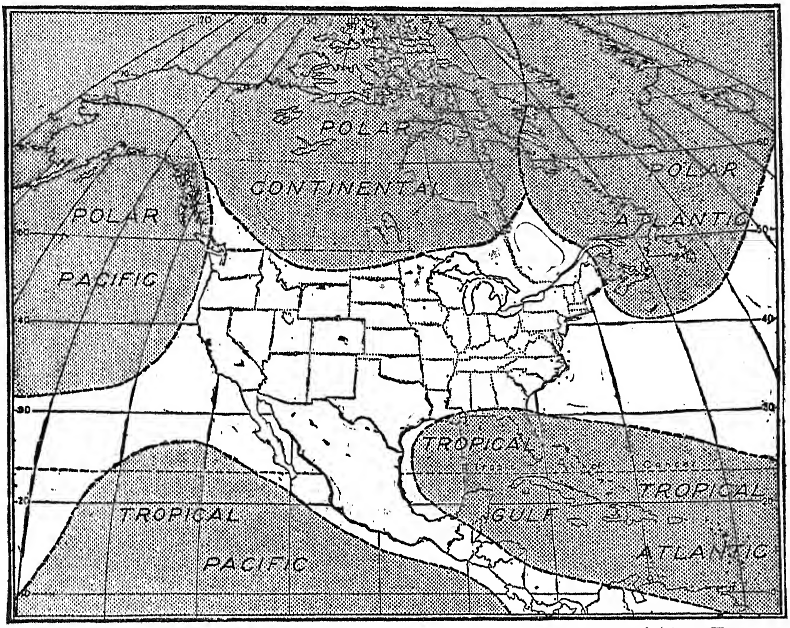


FIG. 72.—Source regions of air masses common to North America. (*After Transcontinental and Western Air, Inc.*)

Figure 72 shows the source regions of air masses common to North America. The *Polar Pacific* (*Pp*) air mass originates in the arctic or subarctic. As it moves over the North Pacific Ocean its moisture content and temperature, at least in the lower layers, are increased somewhat. This air mass along the Pacific Coast often is associated with cloudy weather, with numerous showers, especially in the cool months. After crossing the western mountains its moisture content is much lower. East of the Rockies it tends to produce fair weather with moderate temperatures.

Polar Atlantic (*Pa*) air masses are less important over North America than the Polar Pacific. This is because the prevailing air movement over the continent is from west to east. Along the

Atlantic Coast, from the Carolinas north, Polar Atlantic air may bring unusually cool weather, especially in late spring and early summer.

The *Polar Continental* (*Pc*) air mass moves south over western Canada. It enters the United States mainly through Montana and the Dakotas. This is a typically cool or cold body of air with low absolute humidity. As it moves southward it brings cool

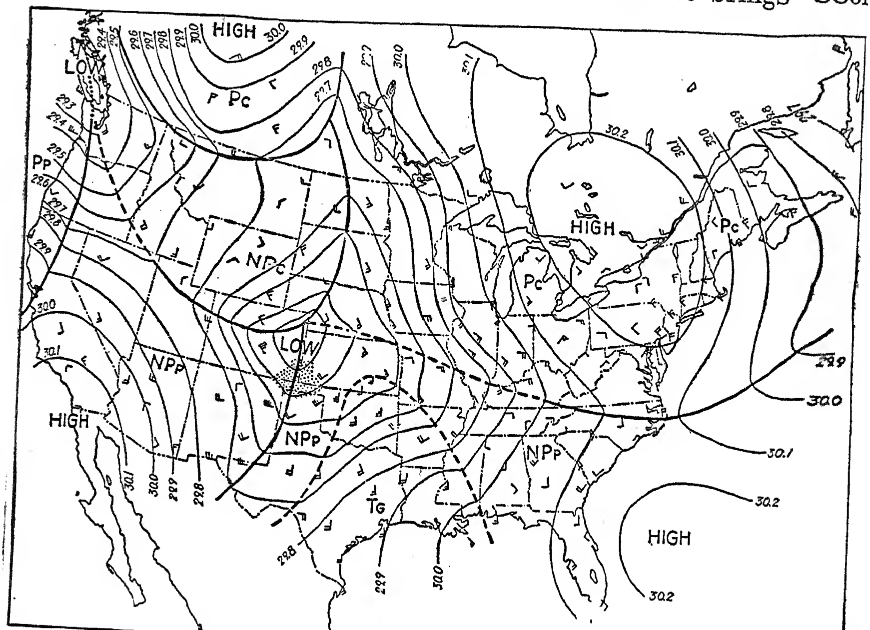


FIG. 73.—Daily weather map. Solid lines indicate cold fronts; dashed lines, warm fronts; stippling, dust-storm area. (*Courtesy of G. R. Parkinson and American Meteorological Society.*)

weather in summer and cold weather in winter. It appears on the weather map as a huge anticyclone, or high. Being of low moisture content, it permits rapid radiation of heat from the earth at night and therefore rapid cooling. As this air mass advances across the continent, its south and east edges are known as the "cold front." It is this cold front that often undermines a Tropical Gulf air mass along the wind-shift line of a cyclone, sometimes producing severe weather changes.

The *Tropical Gulf* (*Tg*) air mass probably originates over the Caribbean Sea or the Gulf of Mexico. It is typically warm and

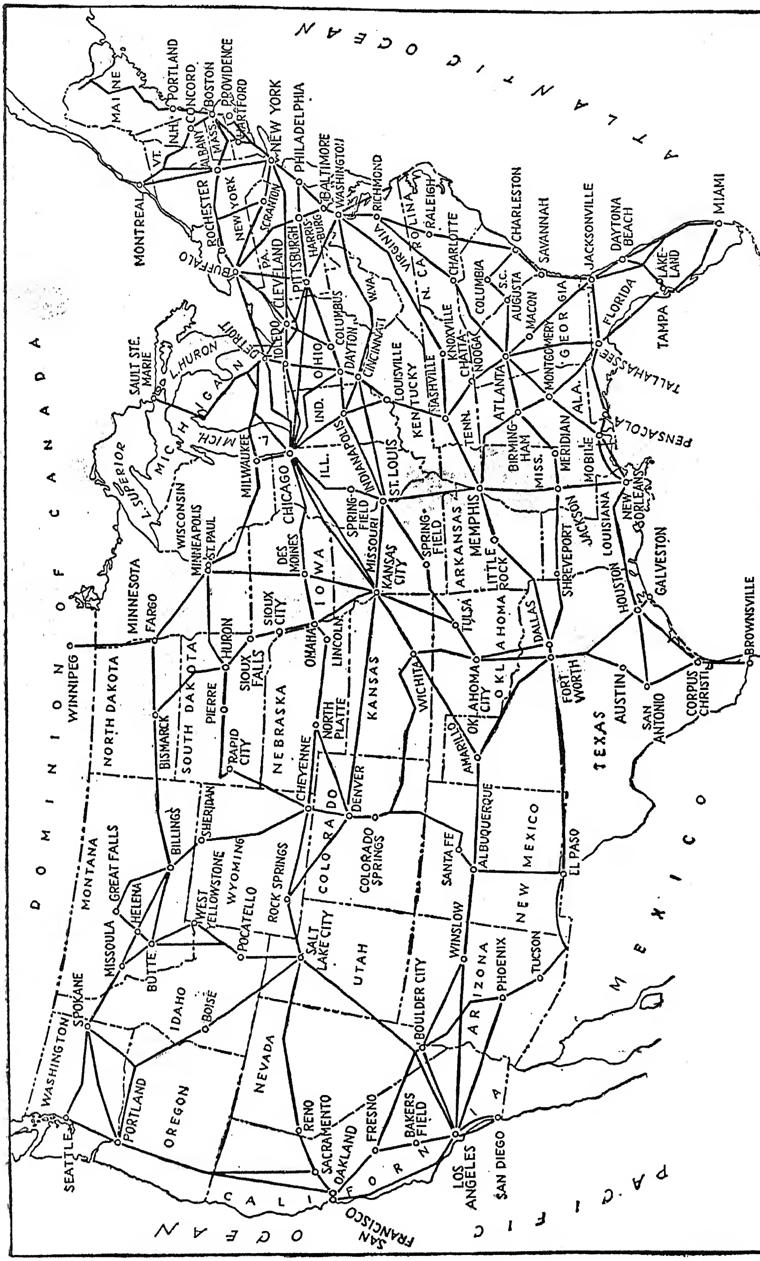


FIG. 74.—Principal air-line routes of the United States. *(Courtesy of U.S. Department of Commerce.)*

humid. As it moves northward, it is the source of much moisture that falls over central and eastern United States. In the warm months, Tropical Gulf air often causes periods of hot, sultry, oppressive weather. When this air mass advances, its northern and eastern edges may form a warm front. It is the warm front that in winter often causes a sharp increase in temperature from zero to 30° or 40° above.

FIG. 75.—Prior to a flight, the pilots and dispatcher lay out a scientific and precise plan for the plane's operation. (*Courtesy of United Airlines.*)

The *Tropical Atlantic* (*Ta*) air mass is somewhat similar to the Tropical Gulf.

The *Tropical Pacific* (*Tp*) or *Tropical Superior* (*Ts*) air mass usually is very warm and dry. Its origin is uncertain. Possibly it comes from the higher levels of the subtropical belt of high pressure over the North Pacific. This hot, dry air, especially in summer, causes rapid evaporation and therefore much damage to crops. *Polar Pacific* air, after crossing western mountains, is also relatively dry and may cause excessive evaporation.

On the daily weather map the letter *N* preceding the symbol of an air mass (such as *NPc*) signifies that the air mass is in a transitional stage. This means that its original characteristics

are being modified or neutralized as it passes over the continent (Fig. 73).

Importance of Weather Information to Aviation. The value of accurate and detailed weather information in the field of aviation cannot be overestimated. Today there are many weather observers along the more heavily traveled air routes (Fig. 74). Thus when local weather conditions suddenly become unfavorable for safe flying, the information is teletyped quickly to the larger airports. There, by means of radio, the informa-

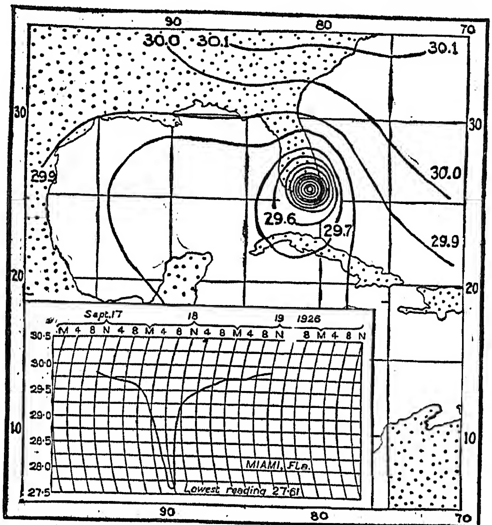


Fig. 76.—A West Indies hurricane.

tion is broadcast to pilots in the air. All airplanes that carry passengers for hire are required by law to be equipped with two-way radio. Pilots can receive and broadcast weather information while in the air. All these precautions, aided by improved weather service, make for greater safety in aviation (Fig. 75).

Tropical Cyclones of the Hurricane and Typhoon Variety

What They Are and Where They Occur. Hurricanes and typhoons are violent tropical storms and are similar except for location. They occur in late summer and early autumn. The *hurricane* originates in the vicinity of the West Indies, travels toward Florida or other Gulf states, and then curves toward the north and northeast (Fig. 76). The *typhoon* occurs in similar

latitudes off the east coast of Asia, traveling across the Philippines toward the coast of China and then turning northward to southern Japan. These tropical storms are much larger than the tornado. Wind velocities usually reach 75 miles per hour or more. The high winds drive great waves of water into coastal settlements. In the center of the storm the barometer has been known to drop more than 3 inches below normal. Excessive rainfall may cause floods. In the hurricane of September 18, 1926, which devastated Miami, Fla., at least 114 lives were lost in the Miami district, and damage to buildings was estimated at nearly 75 million dollars.

These destructive tropical storms appear to occur over the warmer parts of most of the oceans. In addition to the localities mentioned above, the following regions may be noted: (1) the Arabian Sea and the Bay of Bengal, on either side of peninsular India; (2) the South Indian Ocean east of Madagascar; and (3) the tropical waters to both the northeast and the northwest of Australia.

Thunderstorms

What They Are and Where They Occur. A description of the approach and retreat of a thunderstorm is given at the beginning of this chapter. Thunderstorms are characterized by strong upward currents of moist air and the formation of huge cumulo-nimbus clouds. Gusty winds, lightning, thunder, "dash" rain, and sometimes hail accompany these storms. Such an atmospheric disturbance usually is associated with high temperatures at the earth's surface and moist air. Consequently, thunderstorms are most prevalent (1) in certain tropical regions, (2) in the warm season of the intermediate zones, and (3) at the warmer hours of the day. The heavy rain of short duration is a direct result of rapid condensation of water vapor caused by the strong vertical convection currents within the storm.

Types of Thunderstorms. Two types of thunderstorms are usually recognized:

1. *Local heat thunderstorms* may occur without warning, owing to local convection (Fig. 77). Rising air currents cause the formation of towering cumulus clouds. These grow to cumulo-nimbus which may give rise to a thundershower. In central and

eastern United States literally hundreds of these scattered thundershowers may occur on a hot summer day. They are of great economic significance, because they produce much needed rain during the growing season.

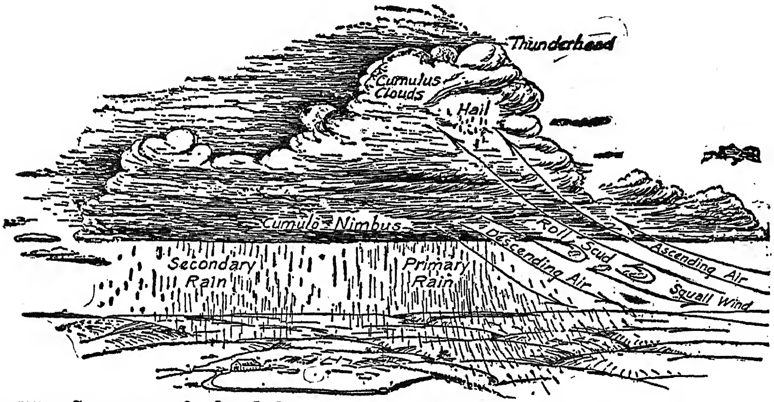


FIG. 77.—Structure of a local thunderstorm. In the United States such storms usually move in a general direction from west to east. (*Courtesy of A. K. Lobeck.*)

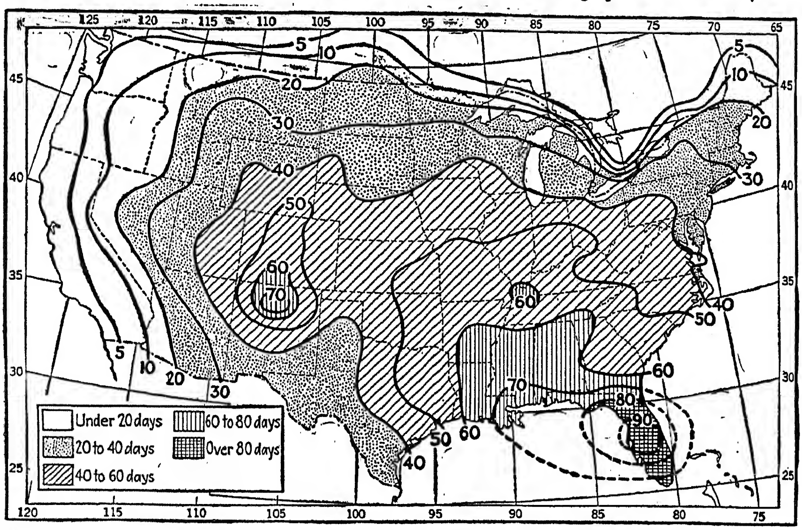


FIG. 78.—Average annual number of days with thunderstorms. (*After Alexander.*)

2. *Cold-front thunderstorms* often are more extensive and more severe than the local heat variety. They occur along the wind-shift lines of well-developed lows during the warm months. As previously explained, the wind-shift line marks the abrupt meeting place of warm- and cold-air masses. The warm-air mass,

which in central and eastern United States often comes from the Gulf of Mexico, may carry much water vapor. As it is suddenly uplifted by the advancing, underrunning cold front of the polar air mass, dark cumulo-nimbus clouds may form. The resulting thunderstorm may be extremely violent, accompanied by heavy rain, lightning, strong winds, and sometimes hail. Such storms may occur at any time of day or night. Because of the dangers involved, these disturbances are avoided by aviators whenever possible. Such a storm usually is followed by cool, clear weather.

High temperatures and stagnant, humid air in the doldrums furnish ideal conditions for thunderstorm formation. Thunder is

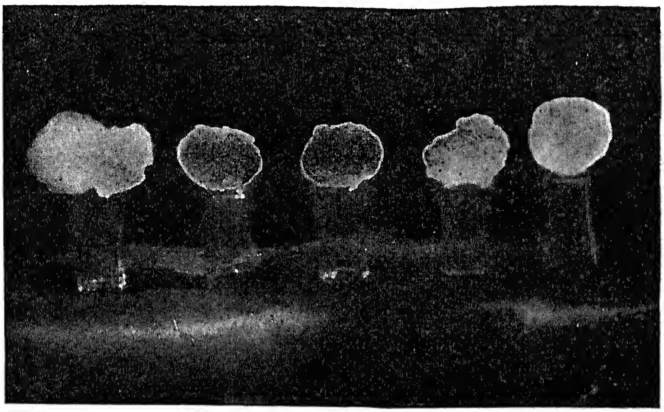


FIG. 79.—Unusually large hailstones. (*Courtesy of S. D. Flora.*)

heard in some doldrum regions 75 to 150 days per year. Deserts in the tropics, however, may have fewer than 5 days with thunder, because of low humidity. In the United States the Gulf states rank highest, and the Pacific Coast lowest, in the number of thunderstorms (Fig. 78). In the middle latitudes such storms are more numerous over land than over sea.

Characteristics of Thunderstorms. *Hail*, the most destructive form of precipitation (see page 92), sometimes accompanies thunderstorms. When convection is most violent, and air currents are ascending at the rate of 25 to 30 miles per hour, raindrops are carried up into regions of extreme cold. They mix with snow and form cloudy globules of ice. Moving downward, this ice is covered with a layer of water and is then shot upward again, and the film of water freezes. This process may continue

until the hailstone, formed of concentric layers of clear ice and snow, like the layers of an onion, reaches considerable size (Fig. 79). When the upward-moving air currents weaken, the hailstones fall to earth. They make dents in automobiles and shatter the glass of greenhouses. Destructive hailstorms often do tremendous damage to growing crops. Many farmers carry insurance to cover such damage.

Lightning is a huge electric spark, caused by the discharge of electricity between clouds or between a cloud and the earth.

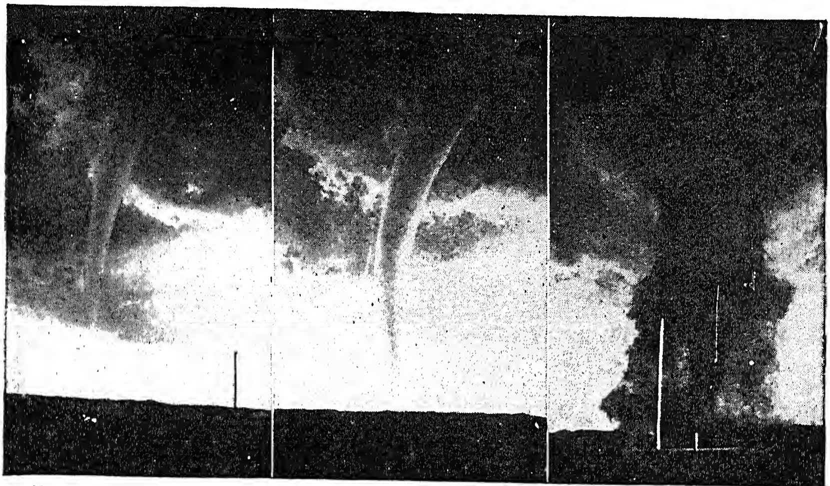


FIG. 80.—Three stages in a tornado that occurred near Gothenburg, Neb., in 1930. In the picture at the left, the tornado's cone is seen as it formed in the clouds; in the center, the fully developed cone as it reached the earth. At the right, the cone strikes a farmhouse, which appears to explode. (*Courtesy of U.S. Weather Bureau.*)

Perhaps you have amused yourself at one time or another by dragging your feet on a rug and then touching someone on the ear. The tiny electric spark that you saw between your finger and the ear was lightning. The faint popping sound was thunder.

Clouds are charged with electricity. The water particles in one cloud may carry a positive charge of electricity, whereas those in another may carry a negative charge. One part of a single cloud may be charged positively; another part, negatively. The electrical discharge caused by these opposite charges usually appears as lightning. Sometimes the electrical discharge takes place between a low cloud and the earth. However, most lightning occurs between clouds. Probably not more than 1 per cent

of the lightning flashes go to the earth. In the United States 700 to 800 persons lose their lives each year as a result of lightning, and double as many are injured. Fire losses due to lightning amount to over 12 million dollars annually.

Thunder is produced by the violent expansion of the air caused by the tremendous heat of lightning. Light waves travel about 187,000 miles per second; sound waves, about 1,000 feet per second. Thus the sound of thunder is heard after the flash of lightning is seen. By counting the seconds between the time the flash is seen and the time the thunder is heard, it is possible to estimate the distance between the observer and the lightning. Sometimes a lightning flash may occur behind a cloud so that the entire cloud is illuminated. This is referred to as *sheet* lightning.

Tornadoes

What They Are and Where They Occur. Tornadoes are the most violent and destructive of all storms, but they are rare and do damage over small areas. They are closely associated with thunderstorms of the cold-front variety in V-shaped lows. The approach of a tornado is usually heralded by dark and greenish masses of cumulo-nimbus clouds in wild turmoil, from which descends the funnel-shaped tornado cloud (Fig. 80). Upper-air currents carry the storm in a general northeasterly direction. The rate of travel averages 25 to 40 miles per hour. Tornadoes occur chiefly in spring and early summer. Destruction of property and life is due mainly to high wind velocities of 100 to 500 miles per hour. Vertical air currents within the tornado are thought to reach velocities ranging from 100 to 200 miles per hour. These storms are typically American. In the United States they are most frequent over the Central and Southeastern states east of the Rocky Mountains. Tornadoes at sea often are called *water spouts*.

Summary

In this chapter we have learned that storms are of tremendous importance because they are the earth's principal generators of precipitation. Thunderstorms are most numerous in the doldrum belt. Cyclones, or lows, and anticyclones, or highs, travel from west to east in the two belts of westerly winds. A

knowledge of storms and of the movements of air masses about lows and highs is of great importance to the weather forecaster. Tornadoes, hurricanes, and typhoons are extremely energetic storms which often cause much loss of life and do enormous damage to property.

Having considered air temperature, pressure, wind belts, humidity, precipitation, and storms, we are ready now to study climate, by which we mean the generalized weather conditions over the earth. There are a number of distinct types of climate to be found on the various continents. The next two chapters deal mainly with descriptions of these climatic types.

Questions

1. Why are storms of special importance over the lowlands of the earth?
2. What is a cyclone? An anticyclone?
3. On a weather map, how is a cyclone shown? An anticyclone?
4. How does pressure change from the center to the edge of a cyclone? An anticyclone?
5. How should you reduce to sea level the barometer reading at a place having an elevation of 1,800 feet? Of 5,850 feet?
6. How do summer cyclones differ from winter cyclones?
7. Why do lows travel in a general easterly direction?
8. What is the speed of lows in summer? In winter?
9. What is the wind direction in the front, or east quadrants, of a low? In the rear, or west quadrants?
10. Why are easterly winds an indication of unsettled weather?
11. Why is the wind-shift line also called the cold front?
12. Why is warm, humid air often forced upward along the surface cold front?
13. Along the wind-shift line of a V-shaped low, what atmospheric disturbances may be experienced?
14. Discuss the wind system of an anticyclone, or high.
15. Why do some lows fail to bring precipitation?
16. Why is there generally little precipitation at the center of a high?
17. Contrast the nature of cyclonic and thunderstorm rainfall.
18. Describe cyclonic weather, especially in the cool months.
19. Why do violent thunderstorms sometimes occur along the cold front? Mention several reasons why aviators avoid severe thunderstorms.

20. What causes a cold wave? A blizzard?

21. What causes a hot wave? What is its effect on evaporation?

22. Contrast temperature conditions in the southeast and northwest quadrants of a low. What temperature change takes place as the storm passes? Why?

23. In which quadrant of a low is humid, "sticky" weather most noticeable?

24. Why does a barometer fall as a storm approaches? Why does it rise as the storm retreats?

25. Name and locate the two tracks along which most lows travel across North America.

26. Write five weather-forecasting rules that, in your opinion, are most important.

27. If wind direction is east and the barometer is falling, from what direction is the storm probably approaching?

28. Explain veering and backing of the wind.

29. What would be the forecast if the barometer was 29.75 inches and falling, and the wind northeast? If the barometer was 30.20 inches and steady, and the wind west?

30. In the study of air masses, what four things are of special interest?

31. What is a radio-meteorograph? An isentropic chart?

32. How are wind velocity and direction aloft ascertained?

33. What is meant by the cloud ceiling?

34. Why is a low cloud ceiling a hindrance to aviation?

35. State two or three facts about each of the following air masses: Polar Pacific, Polar Continental, Tropical Gulf.

36. What does the letter *N* indicate when it precedes the symbol of an air mass?

37. Why is a two-way radio of considerable value on board an airplane?

38. If a well-developed low was in your path, should you fly north or south of the center? Why?

39. Where and when do hurricanes occur? Typhoons? How do these storms differ from tornadoes?

40. What are the characteristics of a thunderstorm?

41. Name the two types of thunderstorm. Briefly describe each.

42. Why are thunderstorms numerous in the doldrums?

43. Where in the United States are thunderstorms most common? Why? Where uncommon? Why?

44. Explain how hail is formed.

45. What is lightning? Explain the cause of lightning.

46. What causes thunder? How can you estimate the distance to a lightning flash?

47. Describe the tornado cloud. What is the wind velocity in a tornado?

48. Where and when do tornadoes occur? Toward what direction do they usually travel?

Suggested Activities

1. Keep a daily weather record. Using a barometer of some kind and a wind vane, make daily forecasts of the weather. Score your forecasts as *correct*, *partly correct*, or *wrong*. If possible, secure the daily weather map from the nearest weather bureau. Make good use of the map to increase the accuracy of your forecasts.

2. Draw a weather map on an outline wall map of the United States. Discuss the forecast for various parts of the country.

3. Secure several copies of the *Monthly Weather Review*, published by the U.S. Weather Bureau, Washington, D.C., and for sale by the Superintendent of Documents. These will give you an idea of the amount of detailed work done by the Weather Bureau.

4. If it is possible to secure the daily weather maps, keep them posted so that the movements of lows and highs can be observed for several days at a time.

5. Study cloud types. They often aid in weather forecasting.

6. Visit a weather bureau or airport, and observe the method of drawing the weather map.

7. Study a map showing air lines. Make inquiry as to the number of weather men employed by the various air-transport companies.

8. If daily weather maps are published in your local newspaper, cut them out, and paste them in a notebook. Paste the official forecast below each map.

NOTE: Other activities may be found in the laboratory manual.

Topics for Class Reports

1. Radio-meteorographs
2. Recent Developments in Air-mass Analysis
3. Distribution of Tornadoes in the United States
4. Hurricanes and Typhoons
5. Weather Service of Transcontinental Air Lines
6. Additional Rules for Forecasting Weather
7. The Value of Weather Forecasting
8. The U.S. Weather Bureau
9. Weather Forecasting on the Pacific Coast

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Chapter VI. Climates of the Tropics and the Dry Middle Latitudes

Sometimes we hear interesting conversations on the subject of climate. Especially is this true when people from widely separated parts of the country get together. The northern Minnesotan can be heard telling about cool summers and cold, invigorating winters, with plenty of snow and ice for winter sports. The Floridian describes his climate as always warm and moist and points to the fact that thousands of tourists spend a part of the winter in Florida in order to avoid the cold of more northerly regions. The southern Californian tells of warm, dry summer days and cool nights and of a winter that really is not winter but instead is a moderately cool season, with snow almost unknown.

The variety of climates over the earth is indeed great. Some, like the tropical deserts, are hot and dry the year round; others, like the coast of southern Alaska, are cool and moist. Some, like much of the United States, have distinct changes of seasons; others, like the equatorial lowlands, have little change during the year. One type of climate may be favorable for the production of bananas; another, for citrus fruits; another, for cereals; and still another, for magnificent forests. Some climates are so severe that people avoid them. Witness, for example, the sparse population of the intensely hot, dry Sahara Desert in northern Africa and of the arctic shores of northern Russia which are bitterly cold much of the year.

Climate, therefore, is a most important element of environment. It has much to do with peoples' daily work habits and with the occupations that they follow.

What about Your Local Climate? Before beginning a study of the principal types of climate that are to be found on the

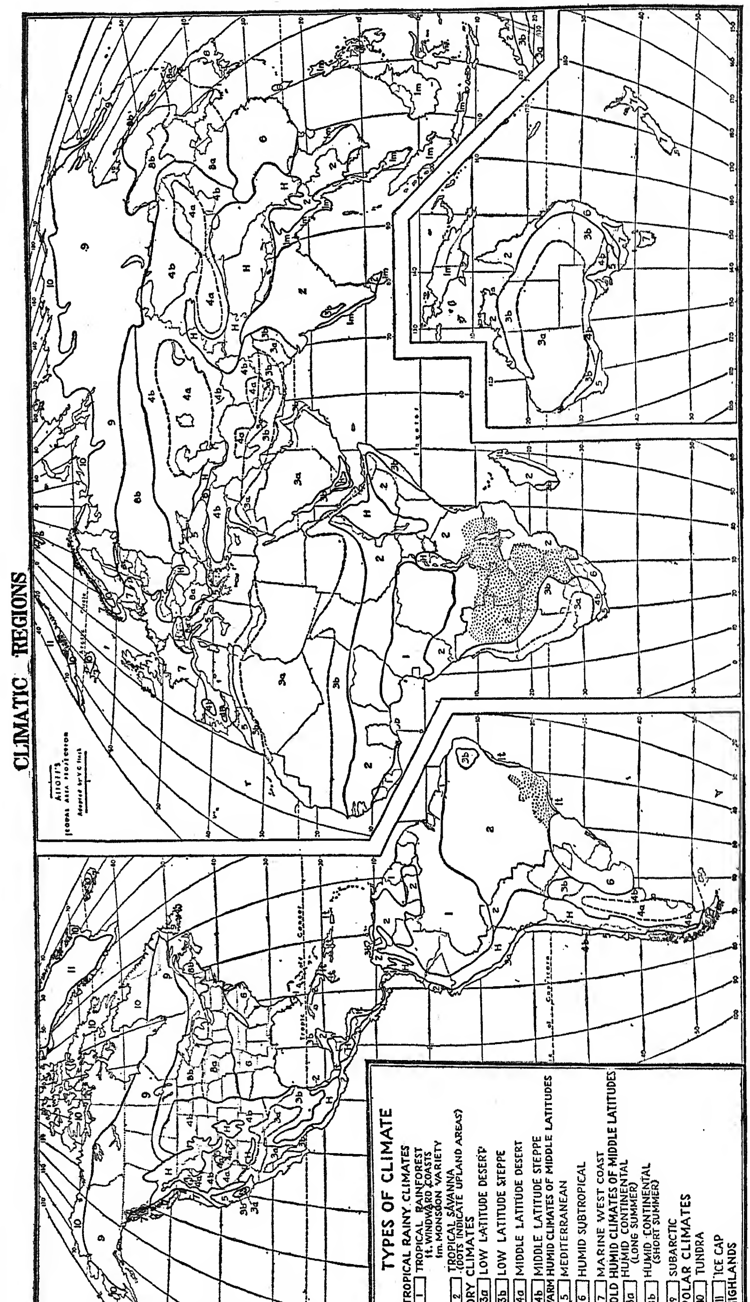

Fig. 81.—Climates of the earth.

earth's surface, you should fix in mind certain facts about your local climate. This knowledge will help you to compare climates in other parts of the world with your own. Such comparisons enable us to understand better the environmental conditions in other localities.

The two most important elements of climate are *temperature* and *rainfall.* What are the temperature and rainfall characteristics of your own local climate? Using data from the nearest weather bureau, learn the answers to the following questions:

1. Which month is the warmest? Coldest?
2. What is the *average* temperature of the warmest month? Of the coldest month?
3. What is the annual range of temperature? The daily range of temperature?
4. What is the highest temperature recorded during the year? The lowest?
5. What is the average annual rainfall?
6. Which season has the most rain? Which month? Which month has least rain?

With these facts in mind for the purpose of comparison, we may give our attention now to the various types of climate on the earth.

Climatic Regions. It is possible to divide the continents into regions, called *climatic regions,* each of which has a certain type of climate (Fig. 81). The location of these regions is made possible by the numerous records of temperature and rainfall that have been kept for many years in many places. (For examples of such records, see Appendix B.) It is important that the information on the seasons given in Appendix A be kept in mind during the study of world climatic regions. Our survey of these regions begins with the tropical climates of the low latitudes (equator to 20° or 30°).

Tropical Rainy Climates

General Considerations. The humid tropics form a somewhat interrupted and irregular "belt" 20° to 40° wide around the earth and straddling the equator. This region differs from all other humid regions of the earth by reason of the fact that it is constantly warm; in other words, it lacks a winter. Within this

climatic group, even the coolest month has an average temperature of 64° or more.

Annual rainfall is rarely less than 30 inches and often exceeds 100 inches. Much of the precipitation is of the convectional, or thunderstorm, type, the heavy showers often being accompanied by severe thunder and lightning. Especially in the wet, tropical lowlands, high relative humidity tends to increase human discomfort. Since the rainfall is mainly convectional in origin, it tends to be greatest at, or soon after, the season of high sun, when the sun is most nearly overhead. On the other hand, rainfall tends to decrease during periods of low sun, or when the sun's rays are more oblique. It is well said, therefore, that in the tropics rainfall follows the sun.

The abundance and intensity of light, both direct and reflected, in the low latitudes are distressing to the eyes. The bright sunlight is also dangerous. To expose the uncovered head to the direct rays of the tropical sun is to invite illness.

The two principal climatic types within the humid tropics differ from each other mainly in the seasonal distribution of precipitation. They are

1. *Tropical rainforest,* having ample rainfall throughout the year.
2. *Savanna,* having distinct wet and dry seasons.

Tropical Rainforest Climate

Characteristics. Hot, humid weather, luxuriant vegetation, buzzing insects, the chattering of numerous monkeys—these brief expressions enable us to picture the tropical rainforest. Here, in places, are to be found great jungles, where trees, vines, and dense undergrowth form a vegetation cover difficult to penetrate. Much of the tropical rainforest, however, is not true jungle.

The two most distinguishing characteristics of tropical rainforest climate are

1. Uniformly high temperature
2. Heavy precipitation distributed throughout the year, so that there is no marked dry season (Fig. 82).

Location. For the most part, this climate is found astride the equator and extending out 5° to 10° on either side. On the

eastern sides of continents, however, where trade winds come from warm oceans, this climatic type may be found 15° or even 25° from the equator. In general tropical rainforest climate coincides reasonably well with the equatorial belt of calms and variable winds, or the doldrums. The principal regions having this type of climate are (1) the Amazon Basin, (2) the Congo Basin, (3) the East Indies and Malay Peninsula, and (4) Panama and the eastern lowlands of Central America.

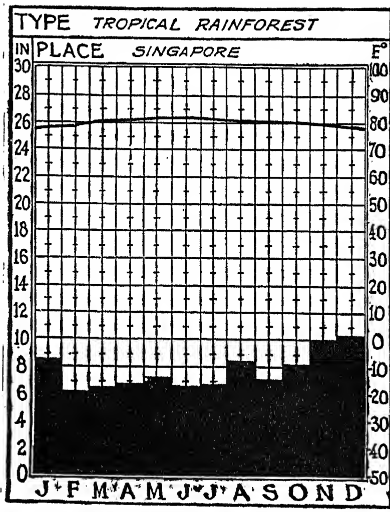

FIG. 82.—Average monthly temperature and precipitation for a representative tropical rainforest station. Monthly temperatures are much more uniform than monthly precipitation.

Temperature. Lying as it commonly does on each side of the equator, and consequently in the belt of greatest insolation, it is to be expected that temperatures in the tropical rainforest climate will be uniformly high (Fig. 83). Annual average temperature usually falls between 77° and 80°. There is little seasonal variation in temperature, because (1) the altitude of the sun is high throughout the year and (2) there is little difference in the length of day and night from one part of the year to another. The annual range of temperature, or difference between the averages of the warmest and coolest months, is usually less than 5°. Thus the annual range at Pará, Brazil, is 3°; Equatorville, central Africa, 2°; and Singapore in southern Malaya, 3.2°. Over oceans in these latitudes the range is still less. A remarkable example is shown by Jaluit in the Marshall Islands, which has a range of only 0.8°. It is evident that an outstanding characteristic of this type of climate is the uniformity and monotony of continuous hot weather.

The daily, or diurnal, range of temperature, or the difference between the warmest and coolest hours of the day, is usually 10° to 25°, or several times greater than the annual range (Fig. 83). During the afternoon the thermometer commonly rises to

temperatures varying from 85° to 93° and at night sinks to 70° or 75°. The highest temperature of the day seldom exceeds 96°, whereas in many midwestern cities of the United States it may reach 105° or more in the summer months. Sensible temperatures are excessively high in the tropical rainforest as the result of high humidity. The weather is sultry and oppressive.

Precipitation. Rainfall is both heavy and well distributed throughout the year, there being no dry season. It is estimated that the average annual rainfall throughout much of the doldrum belt is in the neighborhood of 100 inches. In this region close to the equator, conditions are ideal for rain formation. The trades from northeast and southeast rise above the earth's surface as

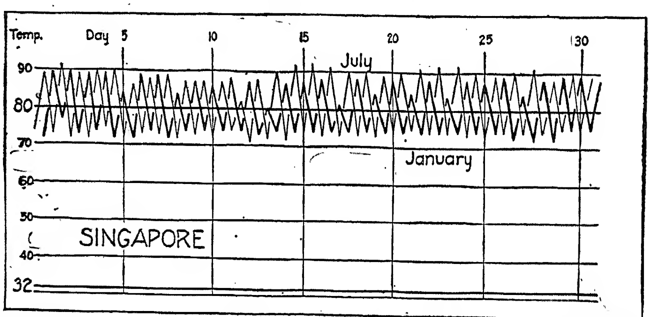

FIG. 83.—Daily maximum and minimum temperatures for the extreme months at a representative tropical rainforest station. The thinner line is July.

they near the equator, leaving a belt of variable winds and calms between them. In this belt of hot, stagnant, moist air, weak tropical cyclones are developed. Local convection produces towering cumulo-nimbus clouds and heavy thundershowers. Mornings are often relatively clear; but as the heat of day increases, cumulus clouds begin to appear. On an average, about 2 days per week have thunderstorms, and several in a single afternoon are not unusual. It is true that there is no genuinely dry season in tropical rainforest climate, yet it should not be inferred that the rainfall is evenly distributed throughout the year. Certain seasons are less wet than others, the variation being due partly to the north-south movement of the sun.

Daily Weather. The following description by an eyewitness is taken from *The Naturalist on the River Amazon* by Henry Walter Bates:

The heat increased rapidly toward two o'clock (92° and 93° Fahr.), by which time every voice of bird or mammal was hushed. . . . The leaves, which were so moist and fresh in early morning, now became lax and drooping; the flowers shed their petals . . . The approach of the rain-clouds was after a uniform fashion very interesting to observe. First, the cool sea-breeze, which commenced to blow about 10 o'clock, and which had increased in force with the increasing power of the sun, would flag and finally die away. The heat and electric tension of the atmosphere would then become almost insupportable. Languor and uneasiness would seize on everyone; even the denizens of the forest betraying it by their motions. White clouds would appear in the east and gather into cumuli, with an increasing blackness along their lower portions. The whole eastern horizon would become almost suddenly black, and this would spread upwards, the sun at length becoming obscured. Then the rush of the mighty wind is heard through the forest, swaying the tree-tops; a vivid flash of lightning bursts forth, then a crash of thunder, and down streams the deluging rain. Such storms soon cease, leaving bluish-black motionless clouds in the sky until night. Meantime all nature is refreshed; but heaps of flower-petals and fallen leaves are seen under the trees. Toward evening life revives again, and the singing uproar is resumed from bush and tree.[1]

Life in Tropical Rainforest Regions. Dense, shady forest with little undergrowth is the typical vegetation cover of much of the virgin tropical rainforest. In old clearings, along streams, and in other places where the sunlight can get through is a jungle growth of trees and underbrush so dense that its penetration is a difficult task. It is here that men make good use of rivers and streams for transportation. The rapid growth of vegetation is a handicap in the construction and maintenance of railroads.

Rainforest climate of the tropics, however, is ideal for the growth of certain economic crops of great value which are native to this type of climate. Especially in the Malay Peninsula and East Indies thousands of square miles are planted in rubber trees. A few rubber plantations are located in the Amazon Basin (Fig. 84). In the eastern lowlands of Central America are to be found great banana plantations (Fig. 85). Lowlands of the Gold Coast, Brazil, and Ecuador contain considerable areas

[1] Bates, Henry Walter. *The Naturalist on the River Amazon*, pp. 31–32, John Murray, London, 1910.

devoted to the growth of cacao trees (Fig. 86). The fruit of this tree is a large pod which contains many beans. These beans, after being dried, are used in making cocoa and chocolate. Sugar cane is an important crop in many parts of the tropics. The cane grows rapidly and can be cut several times per year. A plant of growing importance is the coconut tree. The milk of the coconut is a wholesome food. The dried meat, called *copra*, is shipped to many parts of the world. Coconut oil is valuable not only as

FIG. 84.—Rubber trees in the Amazon Basin. Some of the trees are being tapped. (*Courtesy of Ford Motor Co.*)

a food but also in the manufacture of fine soaps. Tropical rain-forest agriculture in many places, however, is handicapped by poor soil. Many soils are badly leached, meaning that the heavy and continuous rains dissolve and carry away certain valuable plant foods in the soil.

Some kinds of animal life, especially insects, flourish in this type of climate because of the abundant food supply and lack of a winter season. Crocodiles and alligators infest many streams. Among the insects are mosquitoes which act as carriers of malaria and yellow fever. Attacks by hordes of ants often make travel

through the jungle a miserable experience. Monkeys by the thousands chatter in the tree tops.

The natives who inhabit these regions live for the most part from the products of crude and primitive agriculture and from the fish of the streams. Their homes are often small huts with

FIG. 85.—Banana tree in the tropical rainforest climate of Central America. The humid lowlands along the eastern coast of Central America and the island of Jamaica are the heaviest producers of bananas. (*Courtesy of United Fruit Co.*)

steep roofs which quickly shed the heavy rain (Fig. 87). In certain regions these natives are employed on the huge banana, rubber, sugar, or cacao plantations. Density of population throughout tropical lowlands varies but in general is sparse. The great Amazon Basin is one of the most sparsely populated regions of the world. In contrast to Amazonia, however, is the densely populated island of Java.

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sufficient head cover to provide protection against the blazing heat of the sun. Long-continued physical exertion is distasteful,

FIG. 86.—Native workers collecting and opening the pods of the cacao tree. The pods are 8 to 12 inches long and about 4 inches in diameter. Each pod contains 20 to 40 beans, which resemble large shelled almonds. (*Courtesy of Hershey Chocolate Corp.*)

FIG. 87.—A native house in the tropical rainforest of Ecuador. The living quarters are elevated above the ground in order to protect against floods and animals and to give better underventilation. (*Courtesy of Rau Art Studios.*)

however, and the hard work of the plantations is left to the natives, the few white men being employed principally as

overseers and managers. There is the ever present danger of contracting one of the numerous tropical fevers. These must be combated by the frequent use of quinine. Air conditioning of homes and improved sanitary conditions are making life in the tropics more pleasant. In spite of these favorable developments, however, there are few large white settlements within this climatic type.

Climatic Data for Representative Tropical Rainforest Stations

	J	F	M	A	M	J	J	A	S	O	N	D	Yr.	Range
						Singapore, Malay Peninsula								
Temp.	78.3	79.0	80.2	80.8	81.5	81.1	81.0	80.6	80.4	80.1	79.3	78.6	80.1	3.2
Precip.	8.5	6.1	6.5	6.9	7.2	6.7	6.8	8.5	7.1	8.2	10.0	10.4	92.9	
						Pará, Amazon Valley								
Temp.	77.7	77.0	77.5	77.7	78.4	78.3	78.1	78.3	78.6	79.0	79.7	79.0	78.3	2.7
Precip.	10.3	12.6	13.3	13.2	9.3	5.7	4.9	4.3	3.2	2.5	2.3	5.1	86.7	
						New Antwerp, Belgian Congo								
Temp.	79.2	80.1	79.2	78.1	79.2	78.4	76.5	76.3	77.0	77.4	77.9	78.1	78.1	3.8
Precip.	4.1	3.5	4.1	5.6	6.2	6.1	6.3	6.3	6.3	6.6	2.6	9.3	66.9	

Savanna Climate

Location and Boundaries. Savanna climate differs from the tropical rainforest in two respects: (1) it usually has less rainfall, and (2) there are distinct wet and dry seasons. Savannas lie on the poleward sides of the tropical rainforest, between the doldrums on one side and the trades and subtropical highs on the other. They range in latitude from about 5° to 15°. As the vertical rays of the sun move north and south during the year, savannas are alternately influenced by doldrums and trades. Since trades tend to produce deserts, it is evident that savannas occupy a position between constantly wet and constantly dry climates. The llanos of the Orinoco Valley in Colombia and Venezuela and adjacent parts of the Guiana highlands, the campos of Brazil, the Sudan of north Africa, the veldt of south Africa, and portions of northern Australia are all representative savanna lands. Such lands are characterized by tall grass and open forest. Tree growth is heavier on the equatorward side. Poleward we find trees giving way entirely to grassland as the desert is approached. The savanna lands of India, Burma, and French Indo-China are under the influence of monsoon wind systems instead of doldrums and trades.

Temperature. Since the noon sun is never far from a vertical position, constantly high temperatures are the rule in savanna lands. The annual range is usually about 10° or 15°, slightly more than in the tropical rainforest (Fig. 88). In some savanna regions, the inhabitants recognize three temperature periods: (1) the cooler dry season at the time of low sun; (2) the hotter dry season just preceding the rains; and (3) the hot, wet season during the rains. During the cooler dry season, or the period of low sun, day temperatures are high, reaching 80° to 90° in the afternoon. Humidity is low so that the heat is not oppressive. Nights are inclined to be pleasantly mild, the temperature dropping to 60° or 70°. During the hot, dry period, temperatures rise above 90° and often over 100°. The hot, wet season is one of high sun and doldrum influence. It is similar to the tropical rainforest. Daily range of temperature is less than in the dry season, and high humidity makes the weather sultry.

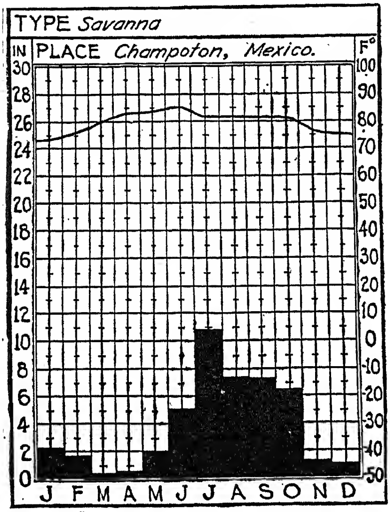

FIG. 88.—Average monthly temperature and precipitation for a representative savanna station.

Precipitation. Savanna lands, with annual rainfall ranging from 40 to 60 inches, receive less precipitation than the tropical rainforest. In contrast to the rainforest, savannas have distinct wet and dry seasons. The Sudan of Africa, which lies just north of the tropical rainforest, may be used to illustrate seasonal distribution of precipitation. As the vertical rays of the sun move north of the equator in April and May, thunderstorms over the Sudan become more frequent. Rainfall continues to increase in amount until July or August, when the doldrums have reached their most northerly position. With the southward retreat of the doldrums, following the sun, rainfall decreases; and by October or November the trades are again in control, and drought again grips the Sudan.

One should keep in mind that south of the equator the period of high sun includes December, January, and February. The period of low sun includes June, July, and August. It is obvious, therefore, that when a Northern Hemisphere savanna is having its rainy season, a drought prevails in the Southern Hemisphere savanna, and vice versa.

SAVANNA CLIMATE

	June to August	*Season*	*December to February*	*Season*
N. Hemisphere	High sun	Wet	Low sun	Dry
S. Hemisphere	Low sun	Dry	High sun	Wet

The hot, wet season is ushered in by violent thunderstorms and severe winds which in Africa are called *tornadoes*. In the dry season, weather is like that of the desert. Humidity is so low that the skin often becomes parched and cracked. In spite of the aridity, the dry weather furnishes relief from the sultry weather of the wet season. As the dry season advances, the landscape becomes brown in color, the trees lose their leaves, the rivers are low, the soil cracks, and all nature appears dormant. Dust and smoke from grass fires often fill the air. The coming of the wet season brings a startling change. Nature responds rapidly to the copious rains of violent thunderstorms. Grasslands are soon green, and the forests clothed with leaves and flowers.

Especially in South Africa and southern Brazil, the savanna lands experience cooler weather because of the higher elevations of plateaus and highlands.

Monsoon Savannas. In India the savanna wet and dry seasons correspond with the periods of onshore and offshore winds, respectively. Winds blow toward land in the warm season, carrying vast amounts of moisture inland. Weak lows move up the Ganges Valley toward the northwest, causing abundant rains. As these onshore winds, loaded with moisture, approach the southern slopes of the snow-capped Himalaya Mountains, the rainfall resulting is the heaviest in the world. Cherrapunji, for example, averages over 400 inches of rain per year and holds the world's record of 905 inches. Over the savanna lands of India the annual rainfall decreases from the eastern coast toward the

northwest. During the period of low sun, winds blow from high-pressure areas over the land toward the sea. This is the dry season during which irrigation is used to provide moisture to growing crops, especially wheat.

Life in the Savannas. Largely as a result of the climatic conditions that prevail, the characteristic natural vegetation of savanna lands consists mainly of tall grass and trees. In some places the grasslands are suitable for the grazing of cattle. In general, however, grazing in the savannas suffers from several serious handicaps, *viz.*, (1) the dry season, (2) the coarse nature of the grass, (3) insect pests, and (4) tropical diseases.

The savanna lands of Africa are the big game regions. A list of wild animals that inhabit the tree and grasslands of Africa would indeed be a long one. Travelers often are astounded at their great numbers. Especially during the dry season, a regular parade of animals can be observed in the vicinity of favorite water holes dotted here and there throughout parts of these regions.

Man lives in the savannas mainly by agricultural and pastoral pursuits. For the most part, these regions in Australia, Africa, and South America are only sparsely populated. This is largely because of (1) the dry season, which in some cases lasts for several months and (2) the lack of dependable rainfall. On the other hand, the monsoon savannas of southeastern Asia support a very dense population. Portions of India are among the most densely populated regions of the world. Here the abundant rains during the wet season and irrigation during the dry season make it possible to produce a tremendous quantity of food, especially from such crops as rice, wheat, and sugar cane. The upland portions of peninsular India are well adapted to cotton production.

In parts of the savanna, man is able to utilize certain valuable trees. In the highlands of southern Brazil, around São Paulo, the coffee tree thrives. In the Gran Chaco, in northern Argentina and Paraguay, quebracho forests furnish not only good timber but also a valuable tanning extract. Commercially, teakwood is one of the most valuable of the savanna trees. This wood is extremely durable and has no equal as a shipbuilding material. It is found in certain highland regions of southeastern Asia.

Climatic Data for Representative Savanna Stations

Timbo, French West Africa (10°40′N.)

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
Temp.	72	76	81	80	77	73	72	72	72	73	72	71	74	9.7
Precip.	0.0	0.0	1.0	2.4	6.4	9.0	12.4	14.7	10.2	6.7	1.3	0.0	64.1	
						Calcutta, India								
Temp.	65	70	79	85	86	85	83	82	83	80	72	65	78	21
Precip.	0.4	1.1	1.4	2.0	5.0	11.2	12.1	11.5	9.0	4.3	0.5	0.2	58.8	
						Cuyabá, Brazil (10°S.)								
Temp.	81	81	81	80	78	75	76	78	82	82	82	81	80	6.6
Precip.	9.8	8.3	8.3	4.0	2.1	0.3	0.2	1.1	2.0	4.5	5.9	8.1	54.6	

The Dry Climates

What Is Meant by a "Dry" Climate? The essential feature of a dry climate is that evaporation shall exceed precipitation. As a result of little rainfall, there is no surplus of water to maintain a constant water supply in the ground. Permanent streams, therefore, cannot originate in such areas. It may be possible for streams to cross them, as do the Nile and the Colorado, provided they have their sources in more humid regions.

Two subdivisions of dry climates are commonly recognized: (1) the arid, or desert, type and (2) the semiarid, or steppe, type. In general, the steppe is a transitional belt, or belt of gradual change, lying between the real desert and the humid climates beyond.

Temperature, Precipitation, and Winds. Temperature changes in the dry climates tend to be greater than in the humid. The daily range is usually large. Clear skies and low relative humidity permit rapid heating of the earth during the day and rapid loss of heat at night. The lack of vegetation in deserts also contributes to the more rapid heating and cooling of the earth's surface.

Rainfall in dry climates is always meager and varies from year to year. Dependability of rainfall usually decreases with decrease in yearly amount. For example, droughts are likely to be more frequent in a region having an annual rainfall of 20 inches than in one having 30 or 40 inches. No part of the earth, as far as is known, is absolutely rainless, although at Arica, on the Pacific Coast of northern Chile, the average yearly rainfall was only 0.02 inch over a period of 17 years. During the entire 17 years only three showers were heavy enough to be measured.

Relative humidity in the dry climates, with a few exceptions, is low, ranging from 12 to 30 per cent during the midday hours. The rate of evaporation is therefore high. The amount of sunshine is great, and cloudiness small. Direct as well as reflected sunlight from the bare, light-colored earth is blinding in its intensity.

Dry regions tend to be windy places. The sparse vegetation offers little resistance to air movement (Fig. 89). Strong convec-

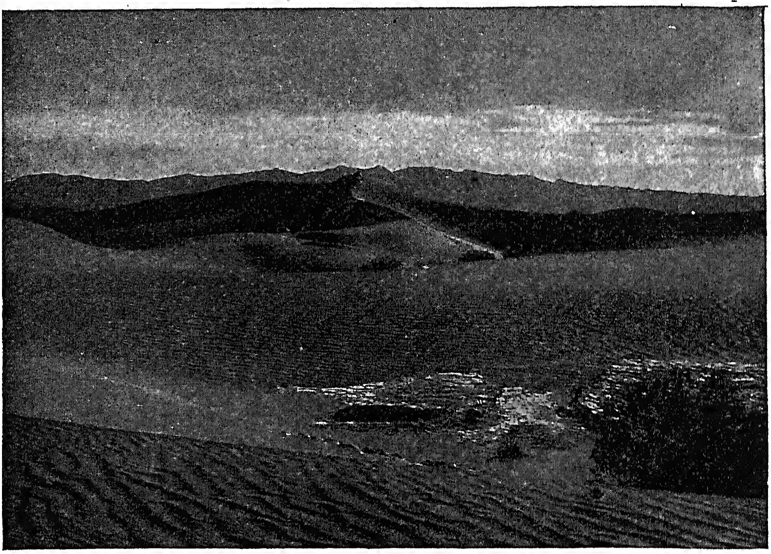

FIG. 89.—The billowing, wind-rippled forms of sand dunes in the American desert. Note the mud floor and some vegetation in the depressions, or pockets, where water has stood. The distant hills in this view are low mountains, not sand dunes. (*Ewing Galloway.*)

tion currents during the day increase the strength of horizontal winds. The air is quieter at night, which is an aid to radiation of heat. Desert air is often murky with fine dust which fills the eyes, nose, and throat, causing serious discomfort. Much of this dust is carried beyond the desert to form the *loess* (wind-blown soils) of bordering regions. Heavier sand and rock particles travel close to the earth's surface. Such wind-blown sand carves some of the peculiar landforms of deserts. The dry climates may be subdivided as follows:

1. Hot (low latitude)
   a. Desert
   b. Steppe

2. Cold in winter (middle latitude)
   a. Desert
   b. Steppe

Low-latitude Desert

Location. These tropical deserts at their extreme margins range from about 15° to 30° of latitude. They tend to occupy centers and western (leeward) sides of the continent in the trades and subtropical highs. It is well to remember that east coasts in the trades are humid and west coasts relatively dry. Cool ocean currents along such west coasts intensify the aridity. The reason for this is explained in a later chapter. The principal low-latitude deserts are (1) the Sahara in northern Africa, (2) Arabia, (3) Thar in northwestern India, (4) the Sonora in northwestern Mexico and southwestern United States, (5) the Kalahari in southern Africa, (6) the Australian desert, and (7) the Atacama-Peruvian Desert along the coast of Peru and northern Chile.

Temperature. The annual range of temperature in tropical deserts is relatively high. At Aswan, in the Sahara, the average July temperature is 95°, and the January temperature 61°, making a range of 34°. The large range is due to the extremely hot summer and not to severe winter cold, as is the case in middle and high latitudes. Daily range of temperature averages 24° to 45° and in rare instances reaches 60° or 70°. The temperature in a single day in parts of the Sahara has been known to range from near freezing to 80° or 90°.

During the months of high sun, scorching, dry heat prevails. The percentage of sunshine is high. Yuma, Ariz., receives 97 per cent of the possible sunshine in June. Midday temperatures of 105° to 110° are common at this season. At Yuma, in 1914, the temperature went above 100° for 80 consecutive days, except for 1 day. Night temperatures are by no means cool, the low readings usually being around 70° to 75°.

At the time of low sun the days are still warm, with the thermometer reaching 60° to 70°, but the nights are distinctly chilly, with minimum temperatures in the neighborhood of 40°. At Insalah, in the Sahara, extreme temperatures for the year have been known to go as high as 124° and as low as 26°. It is

possible, therefore, for light frosts to occur in parts of these low-latitude deserts.

Precipitation. Annual rainfall in the hot deserts averages possibly 5 to 10 inches, although over much of the Sahara it is less than 5 inches (Fig. 90). What rain does fall often comes in the form of violent convectional showers which do not cover a very great area. These heavy downpours may do more harm than good. Dry stream beds are soon filled with raging torrents of water which may damage roads, bridges, or railroads. The immediate runoff of water is excessive. Such dash rains are of little value to the oasis farmer, who uses water from springs and wells to irrigate his crops.

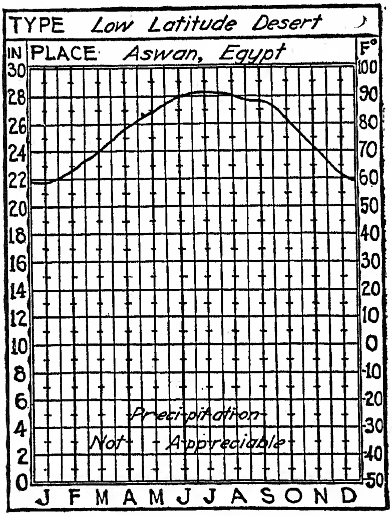

FIG. 90.—Average monthly temperature at a representative station in a low-latitude desert.

Evaporation, caused by high temperatures and low relative humidity, is high. If a pan of water is continuously exposed to the air, the amount evaporated from it may be more than twenty times the annual precipitation. At Yuma the average evaporation during the hot months is 55 inches; the average rainfall during the same period is not quite 1 inch. Relative humidities as low as 2 per cent, with temperatures over 100°, have been recorded in the Egyptian Sahara. It was the excessively dry air that allowed the Egyptians to mummify their dead.

West-coast Deserts in the Tropics. The usual characteristics of tropical deserts are modified somewhat in the west-coast deserts where cool ocean currents parallel the shore. The presence of cool currents is especially marked along the desert coasts of Peru and northern Chile, the southwestern coasts of Africa, and to a lesser degree the northwestern coast of Mexico. Temperatures along such coasts are therefore lower than those of inland deserts at the same latitude. Rainfall is extremely low. Callao, Peru, has an annual rainfall

of 1.8 inches. However, heavy fogs often produce dew and mist. As the cool ocean air drifts landward, the heat of the coastal desert soon evaporates the fogs so that as a rule they do not extend very far inland.

It should be mentioned here that the high evaporation was partly responsible for the preservation of the deposits of sodium nitrate in northern Chile. Water, carrying the nitrate in solution, was evaporated from the desert surface, and the nitrates remain as surface deposits. These nitrates have been shipped from Iquique and Antofagasta to all parts of the world. They are

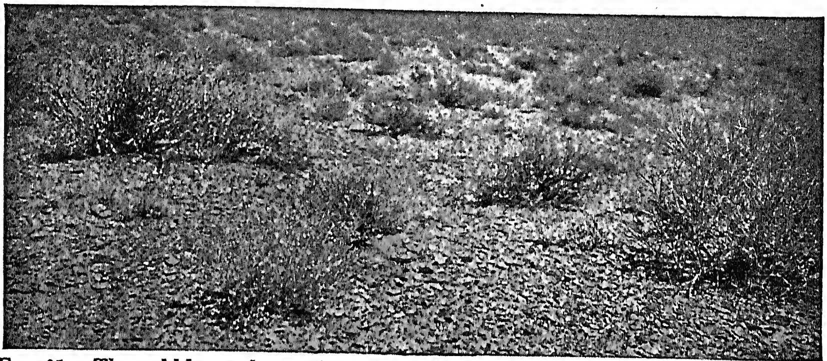

Fig. 91.—The pebbles and rock fragments of a desert pavement in western Nevada. (*Photograph by John C. Weaver.*)

especially valuable in the manufacture of explosives and commercial fertilizers. The nitrate industry of Chile, however, has suffered from the increased manufacture of commercial nitrates in other parts of the world.

Desert Surface. The most characteristic and extensive arid land cover is one of coarse stony or pebbly material (Fig. 91). Loose, shifting sand, often in the form of dunes or hills, covers portions of the desert (Fig. 89). Oasis agriculture is found in limited areas where small deposits of water-carried or alluvial soil are available, provided there is a fairly reliable source of water near at hand.

Where drainage is poor, the rapid evaporation of ground waters may result in the formation of white, alkali soils. Ground water carries chemical matter in solution. As the water evaporates, the white chemical compounds accumulate in the topsoil. This is like boiling salt water. The water boils away, but the

salt remains in the pan. Alkali soils are worthless from the standpoint of crop production.

In general, desert features are sharp and bold. The more resistant rocks may protrude above the general surface, sometimes forming mesas or buttes (Fig. 92). Deep, steep-sided gullies are formed during the occasional torrential downpours of rain. Steep-walled gorges or canyons may be cut by larger streams, called *exotic streams,* which originate outside the desert in more

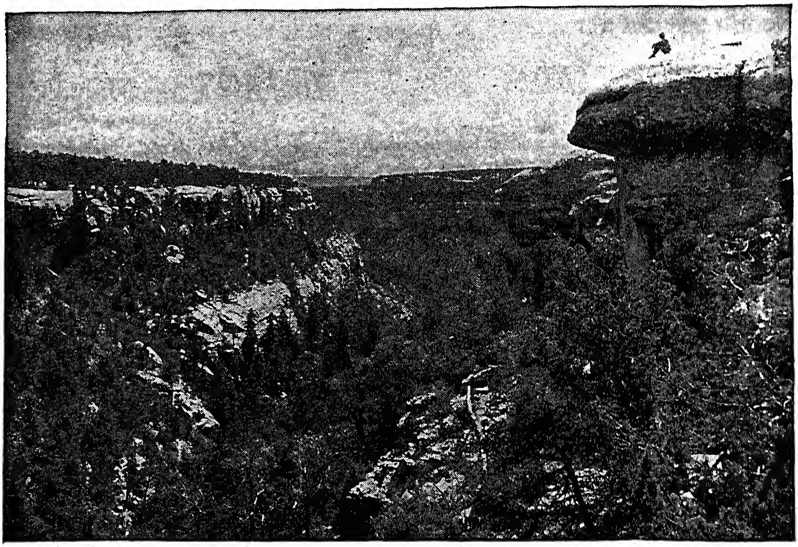

FIG. 92.—View down one of the canyons in Mesa Verde National Park, southwestern Colorado. "Mesa Verde" means "green tableland." The top of the mesa is 1,000 to 2,000 feet above the surrounding territory. The cap rock is red sandstone, underlain by shale. The famous cliff dwellings, used by Indians hundreds of years ago, are in the sandstone layer. (*Courtesy of U.S. Department of the Interior.*)

humid lands. Most arid lands are able to support a scattered vegetation. Desert shrubs such as sagebrush and creosote bush predominate over grassy or weedy plants. In places, various species of cactus form a considerable part of the vegetation (Fig. 93). These arid-land plants are equipped both to resist and to endure drought. Their feeding value is low, although in places goats and sheep are able to find sufficient forage.

Life in the true, tropical desert is indeed hard. Together with certain snow- and ice-covered lands of high latitudes, these are the most sparsely populated regions of the earth. The blistering sun, low humidity, high winds, and sandstorms are

factors that try the endurance of men. Caravans of camels are able to cross the larger deserts by carrying both food and water. Desert tribes in certain localities tend to be nomadic, moving

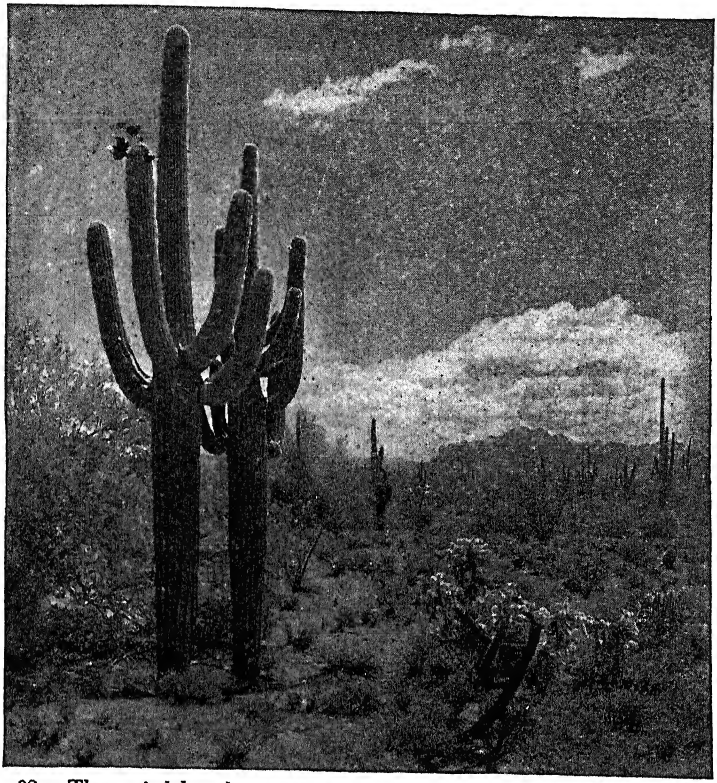

FIG. 93.—The weird but beautiful plants of the Arizona desert testify that this soil is good though dry. In the foreground is a giant cactus. (*Courtesy of U.S. Bureau of Reclamation.*)

from place to place, seeking the meager resources offered by the arid landscape.

CLIMATIC DATA FOR REPRESENTATIVE STATIONS IN LOW-LATITUDE DESERTS

	J	F	M	A	M	J	J	A	S	O	N	D	Yr.	Range
						Jacobabad, India								
Temp.	57	62	75	86	92	98	95	92	89	79	68	59	79	41
Precip.	0.3	0.3	0.3	0.2	0.1	0.2	1.0	1.1	0.3	0.0	0.1	0.1	4.0	
						William Creek, Australia								
Temp.	83	83	76	67	59	54	52	56	62	70	77	81	68	30.5
Precip.	0.5	0.4	0.8	0.4	0.4	0.7	0.3	0.3	0.4	0.3	0.4	0.3	5.4	
						Lima, Peru								
Temp.	71	73	73	70	66	62	61	61	61	62	66	70	66	12.8
Precip.	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.5	0.5	0.1	0.0	0.0	1.8	

Low-latitude Steppe

Low-latitude steppes are semiarid lands, located around the edges of the low-latitude deserts. In northern Africa the steppe lies between the Sahara and Mediterranean climates. On the south edge of the Sahara the steppe lies between the desert and savanna climates. The semiarid regions in northern Australia, southwestern Africa, and northwestern India lie for the most part on the equatorward side of the tropical deserts.

Rainfall in the steppes, like that in the deserts, is not only meager but also variable and not dependable. Humid years attract settlers who later suffer from a series of dry years. Agriculture is safe only under irrigation. Temperature conditions are much the same as in the adjacent desert, with the exception that those steppes on the poleward margins have somewhat lower temperatures during the cool season. These regions as a whole are sparsely populated except in isolated, irrigated spots. During favorable years the grazing of sheep and cattle may provide an occupation for a scattered population. Undependable rainfall and high temperatures are the serious handicaps in these localities.

Climatic Data for Benghazi, Tripoli
Low-latitude Steppe

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
Temp.	55	57	63	66	72	75	78	79	78	75	66	59	69	24
Precip.	3.7	1.8	0.7	0.1	0.1	0.0	0.0	0.0	0.1	0.3	2.1	3.1	11.9	

Middle-latitude Dry Climates

Middle-latitude Desert

Location. Middle-latitude deserts range from about 30° to 45° in latitude. For the most part they lie in the deep interiors of the great continents, far from the oceans which are the principal source of water vapor for the earth's atmosphere. In these latitudes Asia has the largest area of dry climates, and North America is next in order. Aridity is due not so much to the influence of wind belts, as with the tropical deserts, as to location in the *interiors* of large landmasses. It is significant, also, that the middle-latitude deserts tend to occupy depressions, or basins, being surrounded or partially so by highlands or

mountains. Thus the arid Great Basin of Nevada is separated from the Pacific Ocean by the Sierra Nevada Mountains, and to the east lie the Wasatch and Rocky Mountains (Fig. 94). Much of the arid land of Asia is shut off from a possible source of water vapor from the Indian Ocean by the high Himalaya Mountains. Gobi, Tarim, Dzungaria, Russian Turkestan, and central Iran all are surrounded, in part at least, by highland rims.

These deserts, then, are regions of rain shadow and descending winds, so that great aridity is the result. Another result of enclosure, combined with low elevation, is the very high temperature of summer months, sometimes reaching 90° to 110°.

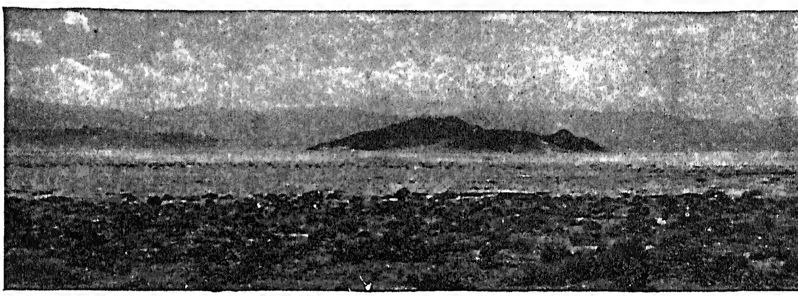

Fig. 94.—An arid basin in Nevada. Its deep alluvial filling has a glistening white crust of salt, and wind-blown salt clings to the rocky island included within it. (*Photograph by John C. Weaver.*)

Patagonia, in Argentina, does not correspond in some respects to the description given above for middle-latitude deserts. There the main cause of aridity lies in the fact that much of southern Argentina is in the rain shadow of the Andes Mountains. A cool ocean current lying offshore likewise induces aridity. Southern South America is so narrow that marine influence is more pronounced, and temperatures in dry Patagonia are by no means so extreme as in the deserts of central Asia or North America.

Temperature and Precipitation. Middle-latitude deserts have a much greater annual range of temperature than do the deserts of low latitudes. Summers are warm, and winters cold. In some places in the deserts of Asia the January average temperature is around 0°, and the July average above 80°. During most of the year the daily range of temperature is considerably

higher than in more humid regions at the same latitude. In winter, continental anticyclones with descending air are rather prevalent over the dry lands, producing cold, clear days with little precipitation. Winds blowing outward from these anticyclones carry low temperatures to localities situated farther south. In the United States a Great Basin high over Nevada, Utah, and Idaho may become anchored for two weeks or more in autumn or winter, warding off storms from the north and producing in the Central states a period of delightful, fair weather. Summer heat tends to develop a seasonal low over the dry interiors of the continents, causing a general inflow of

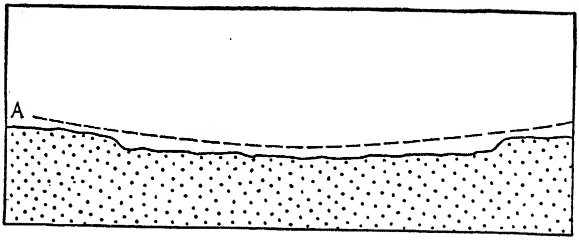

Fig. 95.—A mirage is due to refraction, or bending, of the light rays. An observer at A actually sees an image of the blue sky that comes to his eye along the path shown by the dotted line. This makes the basin appear to contain a lake. The same phenomenon often is seen when one looks down an automobile highway.

winds of monsoonal character. The continents are so vast in size, however, that moisture drawn inland is largely precipitated before it reaches the dry interiors. During the daylight hours in summer, winds are unusually strong in these deserts, a result of convection induced by high temperatures. As with the tropical desert, rainfall is meager. Occasionally in winter the middle-latitude desert is covered with snow. Annual precipitation, however, is usually less than 10 inches. Vegetation is necessarily scanty; and these regions, like the tropical deserts, are among the very sparsely populated portions of the continents.

Mirage. Although mirages have been observed in many parts of the world, they probably have been seen more often in desert and steppe lands than elsewhere. A mirage is due to the refraction, or bending, of light rays. In a flat, basinlike area, the air next to the earth may become much warmer than the air immediately above. The two layers of air, having different

temperatures, also have different densities. As light rays pass through these layers, they are refracted, or bent. A person looking toward the flat basin may be badly fooled. The basin

FIG. 96.—A field of kaffir corn in the semiarid steppe lands of western Kansas. This crop is well adapted to the light rainfall of these regions. It provides feed for several kinds of livestock. (*Courtesy of Kansas State College of Agriculture and Applied Science.*)

may appear to contain a large lake. Actually, because of the bending of light rays, he sees an image of the blue sky (Fig. 95).

CLIMATIC DATA FOR MIDDLE-LATITUDE DESERT

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
					Urga, Mongolia (3,800 Ft.)									
Temp.	−16	−4	13	34	48	58	63	59	48	30	8	−17	28	79
Precip.	0.0	0.1	0.0	0.0	0.3	1.7	2.6	2.1	0.5	0.1	0.1	0.1	7.6	
					Fallon, Nev. (3,965 Ft.)									
Temp.	31	36	41	50	56	65	74	72	61	51	40	32	50.6	42.7
Precip.	0.6	0.5	0.5	0.4	0.6	0.3	0.1	0.2	0.3	0.4	0.3	0.6	4.7	

MIDDLE-LATITUDE STEPPE

Characteristics. Middle-latitude steppes are the semiarid lands between the middle-latitude deserts and adjacent, more

humid regions. Temperature conditions are not greatly unlike those of the desert. The steppes, however, receive more rainfall and are, therefore, somewhat better fitted for human settlement. Settlers are tempted to farm these semiarid lands (Fig. 96). A succession of humid years may bring them partial success, but invariably a series of dry years will follow with disastrous effects.

Location. In North America a considerable area of this type of climate extends from Texas to Canada, lying east of the Rocky Mountains (Fig. 97). Winters are much more severe in the north (eastern Montana) than in the south. This is the high-plains region. Because of the rather level nature of the land and the scarcity of trees, strong winds prevail during most of the year. In winter these high winds, together with near zero temperatures and snow, are elements of the "blizzards" that sometimes occur in the prairie states. In summer, hot south winds are extremely drying. The short grass that is the typical vegetation has added humus to the soil, so that over most of the region soils are fairly rich and, under irrigation, are very productive. As an illustration, the excellent sugar-beet region of eastern Colorado may be cited. The growth of grasses encourages the grazing of sheep and cattle. Wheat production in the region is a gamble with the weather elements.

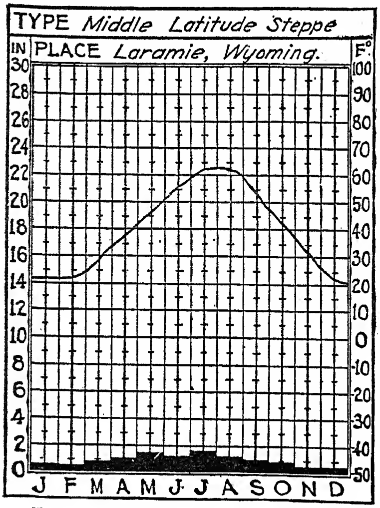

FIG. 97.—Average monthly temperature and precipitation for middle-latitude steppe station.

Two unique features of this climate in North America should be mentioned. One is the *duststorms* which originate in the "dust bowl" in southwestern Kansas and southeastern Colorado, the dust being carried by southwest winds over the Central states (Fig. 98). These storms are not troublesome except during a series of dry years. The other is the *chinook* wind, a warm wind that descends the eastern slopes of the Rocky Mountains and,

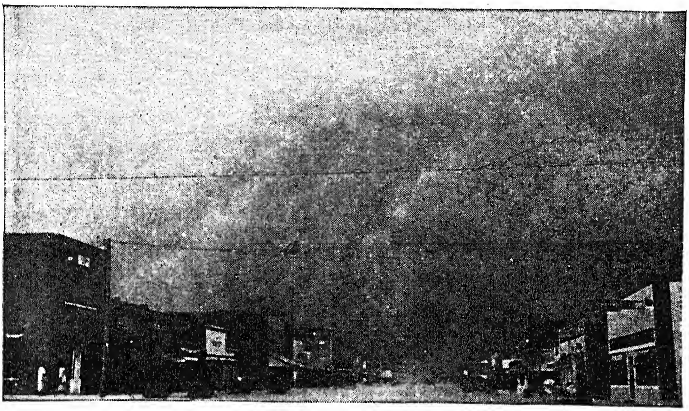

FIG. 98.—A duststorm at Ulysses, in extreme southwestern Kansas. (*Photograph by R. L. Gray, Courtesy of S. D. Flora, U.S. Weather Bureau, Topeka, Kans.*)

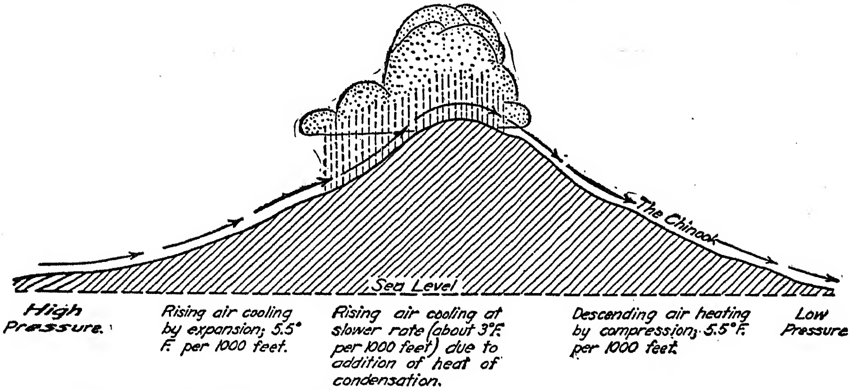

FIG. 99.—Diagrammatic representation of chinook winds. In the Alps this wind is called the foehn.

especially in winter, causes a rapid rise in temperature (Fig. 99). Mainly because of the uncertainty of rainfall, the region as a whole is rather sparsely populated.

CLIMATIC DATA FOR WILLISTON, MONT.

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
Temp.	6	8	22	43	53	63	69	67	56	44	27	14	39.2	62.7
Precip.	0.5	0.4	0.9	1.1	2.1	3.2	1.7	1.7	1.0	0.7	0.6	0.5	14.4	

Summary

Tropical rainforest climate is hot and humid. There is no cool season. Average monthly temperatures differ little during the year. Convectional rainfall in the form of thunderstorms totals

in many places 80 to 100 inches per year. Among the more important economic products of this climate are raw rubber, cacao beans, bananas, coconuts, and cane sugar.

Savanna lands are characterized by a wet season during high sun and a dry season during low sun. Native vegetation consists mainly of coarse grass and scattered trees.

Low-latitude deserts have no winter. At high sun they are extremely hot; at low sun, warm. Middle-latitude deserts have a winter season and therefore a much higher annual range of temperature than do those of low latitudes.

The difference between savanna and steppe is shown in the following chart:

	Annual Rainfall Inches	*Vegetation*
Savanna	30–60	Tall grass and scattered trees
Steppe	10–20	Short grass

The following chapter continues with a discussion of the types of climate to be found in those parts of the world which are farther from the equator than the tropical rainforest or the trade-wind desert.

Questions

Tropical Rainforests

1. How is tropical rainforest climate distinguished from other humid climates?

2. What is the average annual temperature in tropical rainforests? Why is the annual range of temperature so low?

3. Compare the daily range with the annual range of temperature.

4. Make a statement concerning the amount and the seasonal distribution of rain in the tropical rainforest.

5. Why are conditions ideal for rain formation? What is the type of the rainfall?

6. Discuss the daily weather in regions of tropical rainforest climate.

7. What types of clouds predominate in rainforest regions?

8. What is the typical rainforest vegetation? Effect on transportation?

9. Mention a few economic crops and the areas of production.

10. Discuss life in the tropical rainforest.

11. How do white men combat tropical heat? Fever? What is meant by enervating?

12. What problem does the high humidity of the air in the rainforest regions introduce into the practice of air conditioning?

SAVANNA LANDS

13. How does savanna rainfall differ from that of the rainforest?

14. Savannas are influenced by what two wind belts? What is the effect of each?

15. What and where are llanos? Campos? Sudan? Veldt?

16. What three temperature periods are recognized in savannas? Which resembles the tropical rainforest?

17. When does the wet season in the Sudan occur? Why? What is the type of the rainfall?

18. What months constitute the wet season and the dry season in the savannas of the Northern Hemisphere? Southern Hemisphere?

19. What is the effect of the dry season in savannas?

20. Locate the principal upland savannas.

21. Explain the cause of monsoon winds in southeastern Asia.

22. Why does rainfall decrease from Calcutta toward the northwest? It is heaviest during what months?

23. Why does Cherrapunji have such heavy rain?

24. What is the typical vegetation of savannas?

25. Mention several handicaps to the grazing of livestock in the savannas.

26. Name a few economic products of savannas and at least one producing region for each.

DRY CLIMATES

27. What is the essential feature of a dry climate?

28. In general, how does latitude affect rate of evaporation?

29. What are the two subdivisions of dry climates?

30. Why is the daily range of temperature large in deserts?

31. What is a general rule relating to dependability of rain?

32. Locate Arica. What is the annual rainfall there?

33. What are the characteristics of humidity, sunshine, and winds in dry climates?

34. Name and locate the principal low-latitude deserts.

35. Discuss annual and daily range of temperature in low-latitude deserts.

36. What temperature extremes have occurred at Insalah?

37. What is the character of most desert rainfall?

38. How much does evaporation exceed precipitation in some deserts?

39. What peculiar characteristic has the climate of a west-coast tropical desert?

40. How has climate probably contributed to formation of sodium nitrate deposits in northern Chile?

41. Describe the desert surface. What is an oasis?

42. What is meant by an exotic stream? Give an example.

43. Describe desert vegetation.

44. Locate the low-latitude steppes. Why are they sparsely populated?

45. What is the main cause of aridity in middle-latitude deserts?

46. Where is the Great Basin? It is bordered by what mountains?

47. Name the desert regions of Asia.

48. Where is Patagonia? Why is it arid?

49. Contrast annual range of temperature in high-latitude and low-latitude deserts.

50. What is the effect of an anticyclone over the Great Basin?

51. Describe the climate of the Great Plains of North America. Are soils in general rich or poor? Where is the dust bowl? What are chinook winds?

52. Where would evaporation be more severe, in the steppes of Montana or in the steppes of New Mexico? Why? What would be the effect on crop production?

Suggested Activities

1. Display in the classroom three maps of the world, one showing relief, another the planetary winds over the oceans, and a third the annual rainfall of the continents. Discuss as many relationships as possible. Note particularly the regions of orographic rainfall and rain shadow.

2. Plot rainfall and temperature curves for selected places throughout the world. Paste these curves on a large outline wall map of the world with arrows pointing to the exact location of each place.

3. If possible, purchase several large outline wall maps of the United States. Use them to illustrate various climatic conditions throughout the country.

4. Place a pan of water outside a window, and observe the rate of evaporation. Repeat at different seasons of the year. Use coarse screen to keep out birds. At the same time keep a record of sun altitude at noon and the approximate percentage of cloudy and clear weather.

5. Choose one climate among those so far discussed in which you would like to live. Then write a short discussion of this climate, giving reasons for your choice.

6. Paste or pin on a world map the names of tropical economic products in those regions where they are produced in great quantities.

7. Draw a rough outline map of the United States, and superimpose it on a map of the Sahara Desert drawn at the same scale.

8. Summarize the causes of aridity.

9. Label the great deserts on a climatic map of the world.

NOTE: Other activities may be found in the laboratory manual.

Topics for Class Reports

1. Products of the Tropical Rainforest
2. Life in the Amazon Basin
3. The Belgian Congo
4. Plantation Rubber of Malaya and the East Indies
5. Sugar-cane Production in Cuba
6. Cacao
7. Central American Banana Plantations
8. Egyptian Sudan
9. Coffee Production in Brazil and Central America
10. Distribution of Population in India
11. The Use of Savanna and Steppe Lands in Australia
12. The Llanos of Colombia and Venezuela
13. Irrigation Projects in the Steppe Lands of North America
14. Dry Farming in the High Plains of North America

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Chapter VII. Climates of Middle and High Latitudes

"Rain changing to snow; much colder." Thus reads the weather forecast in February. A day or two later comes this warning:

"Florida fruit growers should be prepared to protect trees against freezing weather."

Meanwhile, in California, the news stories tell of unusually heavy rains.

Then comes spring, and we read, "Much warmer tomorrow; thunderstorm probable in afternoon."

Summer arrives, and there are occasional rains. Then, throughout much of central United States, a "spell" of hot, dry weather sets in, and much damage is done to growing crops.

All kinds of weather! Such is the nature of the middle latitudes, or intermediate zones, which extend approximately from the 30th to the 65th parallel. Such variety is in sharp contrast with the monotonous, warm, humid weather of the tropical rainforest. In the tropics, seasons are designated as *wet* and *dry;* in the middle latitudes, as *summer* and *winter*. In the tropics, plants are dormant during the dry season; in the middle latitudes, during the cold, or winter, season.

Cyclones and anticyclones move from west to east in the middle latitudes. They are largely responsible for the changeableness of the weather. It is in these regions that the science of weather forecasting is best developed and most useful.

Our study of these latitudes begins with that type of climate which is found around the shores of the Mediterranean Sea.

Mediterranean Climate

General Features and Location. Blue skies, abundant sunshine, mild winters, and few rainy days are outstanding

features of Mediterranean climate. With such an environment usually is associated a great variety of fruits and flowers at all seasons. World regions having this type of climate are widely known for their numerous resorts and playgrounds.

Mediterranean climate, also called *subtropical dry-summer* climate, in its simplest form, has three principal characteristics:

1. The precipitation is moderate to low in amount, and much of it falls in the winter season, the summer being nearly rainless (Fig. 100).

2. The winter temperatures are mild, but the summers are warm to hot.

3. There is much sunshine in all the seasons, but especially in the summer.

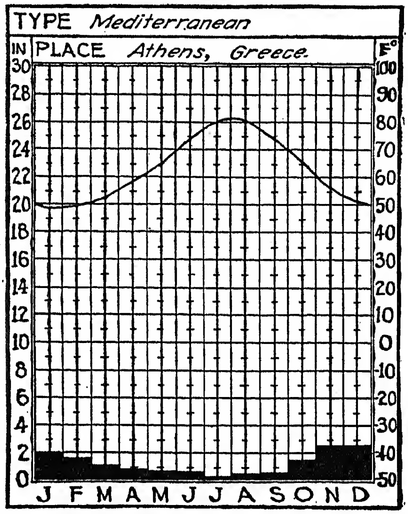

FIG. 100.—Average monthly temperature and precipitation for a representative station with Mediterranean climate.

This type of climate is located on the tropical margins of the middle latitudes. Especially is it found on the western sides of continents, in approximately the latitude of the subtropical highs. This climate, therefore, lies between the dry trades and subtropical highs on the one hand and the humid westerlies with their cyclonic storms on the other. In summer, tropical dry weather is in control; in winter, the changeable weather of the westerlies is the prevailing influence. This, then, is a transition climate between low-latitude steppes and deserts and the cool, marine, west-coast climate farther poleward.

The major regions of Mediterranean climate are (1) the borderlands of the Mediterranean Sea, (2) central and coastal-southern California, (3) central Chile, (4) the southern tip of South Africa, and (5) parts of southern Australia. These areas lie roughly between 30° and 40° of latitude. In central Chile, mountains near the ocean shore confine this climate to a narrow coastal margin. Africa and Australia do not extend southward far enough to have any large areas of Mediterranean climate.

Only in the region of the Mediterranean Basin does this climate extend far inland. In winter, the paths of cyclones move equatorward so that they cross southern Europe. This probably is due to the relative warmth of the Mediterranean Sea. Over this sea there forms an elongated low-pressure area, or "trough." This trough attracts the cyclones which penetrate eastward to Palestine and beyond, bringing cyclonic weather and winter rainfall with them.

Temperature. In a region having Mediterranean climate, more pleasant temperatures throughout the year are likely to be found *along coasts* than farther inland. Summer weather along shore is distinctly cooler. This is caused (1) by the marine influence of ocean winds and (2) in some cases by a cool ocean current that parallels the coast, *e.g.*, in California and Chile. Thus the average temperature of the warmest month at San Francisco is 60°, whereas at Red Bluff in the Sacramento Valley it is 80°. Winters along such coasts are unusually mild, frost being practically unknown. The cold months have average temperatures around 50° to 55°. Annual range of temperature is uncommonly small, approximately 10° at San Francisco and 11° at Valparaiso, Chile. Fogs are frequent, just as they are along desert coasts toward the equator.

Farther inland, Mediterranean climate is somewhat different. Winters are still mild, but summers are distinctly hotter than in coastal regions. At Sacramento, in 1931, there were 27 days in July and 16 in August with maximum temperatures above 90°, highest readings sometimes reaching 105° to 110°. At night, however, the thermometer may record 55° to 60°, showing a great daily range. The relatively cool nights are greatly appreciated by the inhabitants of these regions. In summer the arid heat and glaring sunshine, together with hot, desertlike winds and the parched condition of the vegetation, are disagreeable elements of the landscape.

It is for the mild, bright winters, with delightful living temperatures, that Mediterranean climates are justly famed. People from more severe climates seek them as winter playgrounds and health resorts. Even interior locations have average cold-month temperatures 10° to 20° above freezing. (Sacramento 46°, Marseilles 43°, and Rome 44°.) In southern Cali-

fornia, in January, midday temperatures rise to 55° or 65° and at night drop to 40° or 45°. The growing season is not quite the whole year, because *frosts* occasionally occur during the three winter months, especially in valleys into which cold air sinks. Sensitive crops such as citrus fruits (oranges, lemons, grapefruit) are therefore planted on hillsides. Although severe frosts are rare, there have been instances when freezing temperatures have resulted in widespread disaster to orchardists. For that reason various methods of combating low temperatures are employed when necessary during the cold months. Prominent among such methods is the use of orchard heaters mentioned in Chap. II (see page 38).

Precipitation. Mediterranean climate is unique among world climates in that it is the only one of the humid climates that has a summer drought. Annual rainfall averages 15 to 25 inches. There is a pronounced maximum during the *cooler* months, summer being nearly, if not absolutely, dry. The yearly amount increases with latitude. Thus San Diego has 10 inches of rain per year on the average; Los Angeles, 16; and San Francisco, 23. In all Mediterranean regions snow is so rare that it is a matter of considerable comment when it does fall. It is rather fortunate that the rains occur in the cool season. If they fell during the hot season, much more moisture would be lost by evaporation and thus would not be available for plant growth.

The winter rainfall is due largely to the influence of cyclones which move farther equatorward at that season of the year. There are "spells of weather" when dull, gray skies prevail. Showers fall at intervals. Occasionally the rain becomes a downpour for a short period, sometimes causing floods which do great damage. Thunderstorms seldom occur except possibly in the mountains or hills, two to four a year being the usual number in southern California. The winter rains brighten the landscape, the growth of vegetation changing the prevailing color from brown to shades of green.

Seasonal Weather. Summer weather changes little from day to day. It is characterized by clear skies, drought, brilliant sunshine, high daytime temperatures, rapid cooling at night, and, except near the coast, low relative humidity. Certain regions

in Mediterranean climates are famous for sea breezes, winds that blow from sea to land and have a moderating effect on the intense heat. In autumn and winter the days are bright except for the occasional periods of cloudy, rainy weather. Along coasts, fogs appear in the morning, but the sun evaporates them by nine or ten o'clock. The coast of California is one of the foggiest areas in the United States. Spring is a delightful season, fresh and yet warm. On the whole it is cooler than autumn.

FIG. 101.—Orchards in the Sacramento Valley. (*Courtesy of Sacramento Chamber of Commerce.*)

This is the time when many grains are harvested. As the season advances, rainy spells become rare, and the heat more intense.

A low-pressure area crossing Europe may draw hot winds northward from the Sahara Desert. These winds, called *siroccos*, with temperatures of 100° or more and humidities of 10 to 20 per cent, may do serious damage to vegetation.

Life in Mediterranean Climate. Native plants in this climate are of necessity drought resistant. Trees tend to be widely spaced, not tall, and covered with a thick bark which serves to retard evaporation. Leaves are small and leathery, characteristics that prevent rapid loss of water. Among these drought-resistant trees is the valuable cork oak. Produced

mainly in Portugal and western Spain, the bark of this tree furnishes the world's principal supply of cork.

In some localities the vegetation cover consists principally of a mixture of shrubs and bushes. This is the chaparral of California. Such a vegetation cover is not capable of supporting abundant animal life. However, the meager forage seems to be sufficient in many places for the needs of sheep and goats; and Mediterranean lands, especially in southern Europe, are noted for their large numbers of these animals.

Man combats the semiarid nature of Mediterranean climate by means of irrigation. Under the bright sun, vineyards and citrus-fruit orchards flourish (Fig. 101). In California the rich soils that have accumulated at the base of mountain slopes are so utilized. The hot sun and dry air of the interior valleys are climatic factors that are largely responsible for the development of the fruit-drying industry in certain localities, *e.g.*, around Fresno, Calif. The exporting of enormous quantities of wine from countries bordering the Mediterranean Sea is a direct result of a climate favorable to grape production.

Climatic Data for Representative Mediterranean Stations

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
						Red Bluff, Calif. (Interior)								
Temp.	45	50	54	59	67	75	82	80	73	64	54	46	62.3	36.3
Precip.	4.6	3.9	3.2	1.7	1.1	0.5	0.0	0.1	0.8	1.3	2.9	4.3	24.3	
						Santa Monica, Calif. (Coast)								
Temp.	53	53	55	58	60	63	66	66	65	62	58	55	59.5	13.6
Precip.	3.5	3.0	2.9	0.5	0.5	0.0	0.0	0.0	0.1	0.6	1.4	2.3	14.78	
						Perth, Australia (Coast)								
Temp.	74	74	71	67	61	57	55	56	58	61	66	71	64	19
Precip.	0.3	0.5	0.7	1.6	4.9	6.9	6.5	5.7	3.3	2.1	0.8	0.6	33.9	

Humid Subtropical Climate

General Features and Location. Humid subtropical climate differs from *dry* subtropical, or Mediterranean, climate in three respects:

1. It usually is located on the east sides of continents.
2. It has more abundant rain.
3. The rainfall is either well distributed throughout the year or concentrated in the warm season.

These two subtropical types of climate have about the same latitudinal location, the humid east-coast type ranging from 25°

to 40°. West coasts in the intermediate zones feel the marine influence of westerly winds from the ocean. East coasts also experience westerly winds. However, east coasts are subject to winds having a monsoon tendency, *i.e.*, winds blowing from sea to land in summer and from land to sea in winter. The larger the continent the greater the extremes of temperature near its center. The greater the extremes of temperature the more pronounced will be the monsoon winds, because great temperature differences mean great pressure differences. Thus Asia and North America are continents in which the monsoon tendency is relatively well developed. The stronger the monsoon tendency the greater the concentration of precipitation in the warm season.

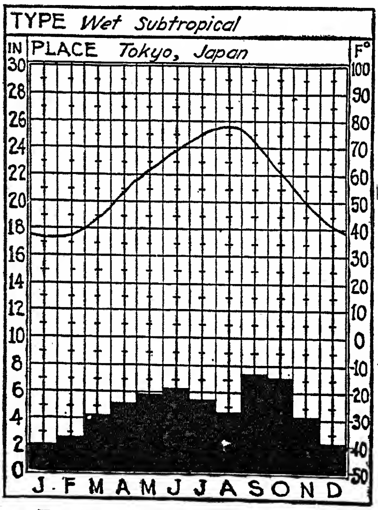

FIG. 102.—Average monthly temperature and precipitation for a representative station in the humid, or wet, subtropics.

The larger areas of humid subtropical climate are (1) southeastern United States; (2) Japan and eastern China; and (3) northern Argentina, Uruguay, and extreme southern Brazil. Smaller areas are found in southeastern Africa and Australia.

Temperature. The temperature characteristics of humid subtropics are somewhat similar to those of Mediterranean climates, since they occupy about the same latitudes. However, warm ocean currents along east coasts prevent such cool, foggy weather as that of San Francisco and other west-coastal locations.

Summers are warm to hot, typical average temperatures for the warmest months being 75° to 80° (Fig. 102). Relative humidity, as well as temperature, is high, producing a sultry, oppressive condition. Sensible temperatures, therefore, especially in summer, are higher in Florida than in California. Summer heat in the American Gulf states closely resembles that of the tropical rainforest. In the subtropical regions of China and

Japan, Europeans and Americans frequently quit their usual places of residence during the summer and go to high-altitude stations, as they do in the genuine tropics. Nights are hot and humid in contrast to the drier and cooler nights of Mediterranean climate.

Winters in the humid subtropics are relatively mild. Cool-month temperatures average 40° to 55°. The annual range of temperature is, therefore, usually not great, ranging from 20° to 30°. Nights may be uncomfortably chilly because of high humidity and a temperature around 40°.

The growing season, or period between killing frosts, is long, ranging from 7 months up to nearly, if not quite, the entire year. Freezing temperatures occur on only a relatively few nights in winter. The cold spells do serious damage to sensitive crops such as citrus fruits and sugar cane. Cold waves are more severe in the American Gulf states than in southeastern China. This is because (1) winter cyclones and anticyclones of North America are well developed and (2) the level nature of the land surface permits the cold air from northern Canada to flow southward toward or even to the Gulf of Mexico (Fig. 103). The extreme southern tip of Florida is the only place in the United States where the thermometer has never been known to reach 32°.

Precipitation. Rainfall is relatively abundant within the humid subtropics, annual amounts ranging from 30 to 65 inches. Rain falls throughout most of the year but in general is heavier in the summer months.

Summer rainfall is mainly convectional, accompanied by thunder and lightning. The humid subtropical region of southeastern United States ranks high in thunderstorms, the annual number ranging from 60 to 90. Hurricanes and typhoons are late summer and early autumn storms characteristic of this climate. They bring torrential rains and floods, which, with high winds, may do tremendous damage. In the Swatow typhoon of August, 1922, it was estimated that 40,000 Chinese lost their lives, chiefly by drowning.

Winter rainfall is mainly cyclonic in origin. It is usually associated with a general and persistant cloud cover extending over wide areas. Because of more numerous cyclones, winters

are cloudier than summers. Gray, overcast days are unpleasantly chilly. Snow falls occasionally but melts within a day or two.

Humid Subtropics Are Highly Productive. Without doubt these regions possess the most productive climate of the middle latitudes. There is little restriction upon the kinds of crops that can be grown. Winter cropping is nowhere prohibitive.

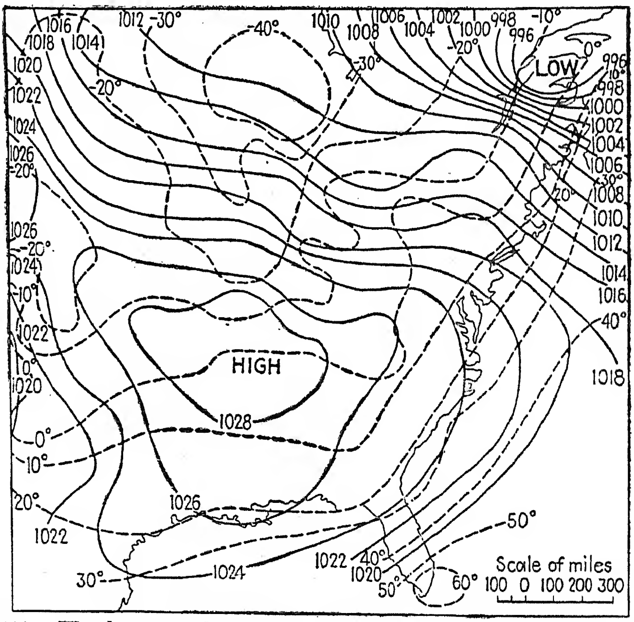

FIG. 103.—Weather controls giving rise to killing frosts in the American humid subtropics. A well-developed anticyclone advancing from the northwest as a mass of polar continental air produced minimum temperatures of 20° at New Orleans and 8° at Memphis. The isotherm of 20° fairly well parallels the Gulf and South Atlantic Coasts.

In southern China and Japan, many of the fields are in use the entire year. The lack of a cold season, however, tends to increase crop losses from injurious fungus and insect pests.

The abundant warmth and moisture cause an equally abundant vegetation cover, usually of forests; although in regions of more moderate rainfall, grasses may replace trees. Grasslands, for example, predominate in the pampa of northern Argentina. In China, the forests have been cut to such an extent that soil erosion and floods are serious problems. The South

Atlantic and Gulf states of America possess considerable forest resources, although the stand of pine trees has rapidly diminished. Much of the land from which southern pines are being removed is so poor that it is unfit for agriculture.

FIG. 104.—Cotton growing on the flat coastal plain of Texas. (*Courtesy of Agricultural Experiment Station, A. and M. College of Texas.*)

In general, the forest soils of the Gulf states are not of high fertility. This is due largely to the solution and removal of soil materials by abundant rains.

It needs to be emphasized, however, that in those areas where soils are fairly rich, humid subtropical climate is capable of tremendous agricultural production (Fig. 104). This is shown by the rice-producing delta regions of China and the black soils

CLIMATIC DATA FOR REPRESENTATIVE HUMID SUBTROPICAL STATIONS

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
						Charleston, S. C.								
Temp.	50	52	58	65	73	79	82	81	77	68	58	51	66.1	31.4
Precip.	3.0	3.1	3.3	2.4	3.3	5.1	6.2	6.5	5.2	3.7	2.5	3.2	47.3	
						Shanghai, China								
Temp.	38	39	46	56	66	73	80	80	73	63	52	42	49	42.8
Precip.	2.8	2.0	3.9	4.4	3.3	6.6	7.4	4.7	3.9	3.7	1.7	1.3	45.8	
						Sydney, Australia								
Temp.	72	71	69	65	59	54	52	55	59	62	67	70	63	20
Precip.	3.6	4.4	4.9	5.4	5.1	4.8	5.0	3.0	2.9	2.9	2.8	2.8	47.7	

of the cotton belt of the United States. The supplying of northern markets with citrus fruits and off-season vegetables and the operation of winter resorts for tourists illustrate other opportunities for human occupation in the American Gulf states.

Marine West-coast Climate

Location. Marine climates occupy positions on *western,* or *windward,* sides of middle-latitude continents, poleward from about 40°. Onshore westerly winds import to them conditions from the oceans. In their general atmospheric characteristics, therefore, they are like the seas from which the imported air is arriving. Where land areas are relatively narrow, as with Great Britain, New Zealand, and Tasmania, the marine influence is felt inland as well as along the coast.

Because of higher latitude, marine coasts are *not* subject to the very dry seasons found in Mediterranean climates. Moreover, marine coasts are usually paralleled by relatively warm ocean currents. Evaporation of water from these currents increases the moisture content of the winds that move from sea to land in these regions.

The depth to which marine west-coast climates penetrate inland depends upon the nature of the land surface. Where mountains closely parallel the west coasts as in North America, South America, and Scandinavia, oceanic conditions are confined to relatively narrow coastal strips. But where extensive lowlands prevail, as in parts of western Europe, the effects of the sea are carried well inland.

Temperature. Summers are moderately cool and, although more or less ideal for human efficiency and comfort, are on the other hand somewhat too cool for the best growth of many cereal crops. These cool summers are in severe contrast to the hot summers of Mediterranean and humid subtropical climates. In these cloudy, rainy regions the daily range of temperature is small. In Seattle the highest temperatures of the day in July average 73°, and the lowest average 51°. Occasional hot days occur, but prolonged hot waves are very few.

Winters, on the whole, are abnormally mild for the latitude. Especially is this true in western Europe where a great mass of warm water, known as the *North Atlantic Drift,* a continuation

of the Gulf Stream, lies offshore. Thus most marine parts of western Europe are 20° to 30° too warm in January for their latitudes. Hammerfest, on the coast of Norway, 71°N., is an ice-free port, yet ice-breakers are required to keep open the harbor of Hamburg, 54°N. but considerably inland from the Atlantic. It is rare for London to have a temperature below 15°. The frost-free, or growing, season is unusually long for the latitude, being 180 to 210 days in the American North Pacific Coast region.

Precipitation. Marine west coasts generally have adequate rainfall at all seasons (Fig. 105). The total amount varies, depending much upon the surface features of the land. Over the lowlands of western Europe, the rainfall is only moderate, usually 20 to 40 inches. On mountainous coasts, however, the total may reach 100 to 150 inches. Europe is the only continent where marine rainfall extends inland to any great distance. In North America heavy precipitation on the west side of the Cascades is counterbalanced by arid to semiarid conditions to the east.

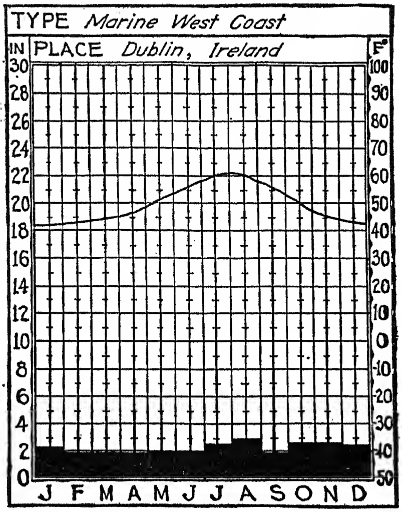

FIG. 105 —Average monthly temperature and precipitation for a representative station in marine west-coast climate.

Rainfall on marine west coasts has two outstanding characteristics: (1) It is reliable, droughts being of rare occurrence, and (2) it is adequate for plant growth at all seasons. Usually there is no marked dry season. In some places, especially along mountain coasts, winter precipitation is much heavier than that of summer. Snowfall is not abundant over the lowlands of northwest Europe because of temperatures that are prevailingly above freezing. On the western slopes of the Cascades, however, 300 to 400 inches of snow fall on the average each year. Snowfall is likewise heavy in the southern Andes, in the mountains of New Zealand, and along the coast of British Columbia and southern Alaska.

Marine coasts are well known for cloudy weather. The Puget Sound region has the highest cloudiness and least sunshine of any part of the United States. Over western Europe, cloudiness over wide areas is greater than 70 per cent, the sun sometimes

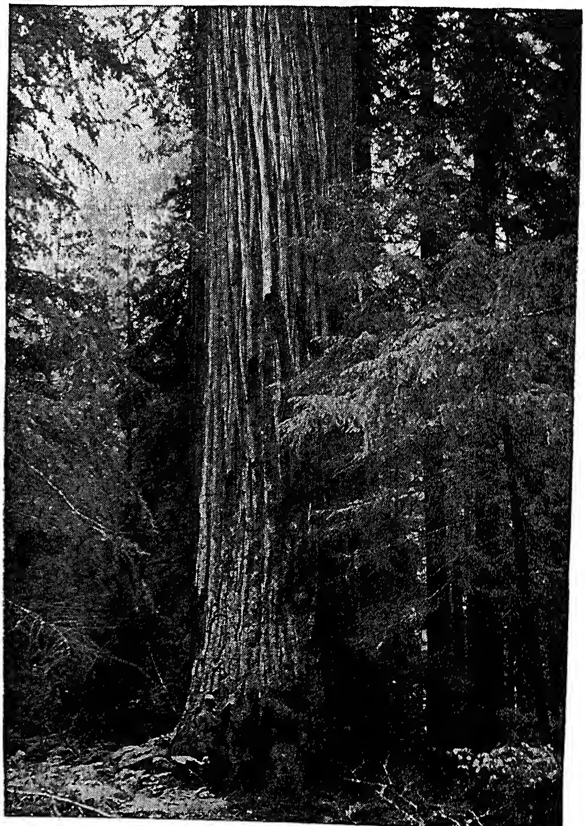

FIG. 106.—This large California redwood tree (*Sequoia sempervirens*) is over 12 feet in diameter, measured 5 feet above the ground. (*Courtesy of U.S. Forest Service.*)

being hidden for several weeks in succession. Evaporation, therefore, is very low, so that small amounts of rainfall are very effective for plant growth. Relative humidity is almost always high.

Productivity of Marine West Coasts. In this mild, humid climate, forests and pasture lands are of excellent quality. The finest stand of timber in the United States is found along the northern Pacific Coast. In northern California, occupying

the foggy, western slopes of the Coastal Ranges, are the great redwood forests (Fig. 106), but pines and cedars prevail inland. Farther north, in Oregon, Washington, and southern British Columbia, Douglas fir is the outstanding tree, being the most important timber tree of the Pacific Coast forests. North of about latitude 50°, in British Columbia and Alaska, fir is less abundant, and spruce and western cedar become the dominant timber trees. Of the remaining stand of saw timber in the United States, about 60 per cent is in the Pacific Coast forests.

The cool, damp climate of marine west coasts is well suited to the growth of many grasses. The excellent pasture lands that abound in some regions have encouraged livestock production. Thus most of the breeds of fine livestock have been developed in the countries of western Europe.

Soils in regions of marine west-coast climate vary considerably but in general are only moderately fertile. The various types of soil are responsible to some extent for the variety of agricultural crops produced. The forest soils in general are superior to those of the tropical rainforest. In many places the soils have been influenced considerably by past glaciation. Especially in Oregon and Washington, many of the more fertile valleys are important fruit-producing regions, an example being the Rogue River Valley.

Climatic Data for Representative Marine West-coast Stations

	J	F	M	A	M	J	J	A	S	O	N	D	Yr.	Range
Seattle, Wash.														
Temp.	40	42	45	50	55	60	64	64	59	52	46	42	51.4	24
Precip.	4.9	3.8	3.1	2.4	1.8	1.3	0.6	0.7	1.7	2.8	4.8	5.5	33.4	
Paris, France														
Temp.	37	39	43	51	56	62	66	64	59	51	43	37	50.5	27
Precip.	1.5	1.2	1.6	1.7	2.1	2.3	2.2	2.2	2.0	2.3	1.8	1.7	22.6	
Hokitika, New Zealand														
Temp.	60	61	59	55	50	47	45	46	50	53	55	58	53	16
Precip.	9.8	7.3	9.7	9.2	9.8	9.7	9.0	9.4	9.2	11.8	10.6	10.6	116.1	

Humid Continental Climate

Location. Humid continental climates are limited to North America and Eurasia. There is no landmass in the south intermediate zone sufficiently large to have this type of climate. In Europe marine climate extends to eastern Germany, where it gradually changes to humid continental. In North America

mountain barriers that parallel the western coast cause arid to semiarid conditions over much of the western half of the continent. Therefore humid continental climate is found mainly in the eastern half of North America, extending roughly from southern Missouri to southern Canada and from central Kansas to the Atlantic.

This severe climate is land controlled. It is carried to the east margin of the continents by westerly winds. The east coasts do not experience quite so severe temperature changes as do the mid-continental areas, but their climate is, nevertheless, much more continental than marine. A third segment of this climatic type is found in North China, Manchuria (Manchukuo), and southeastern Siberia.

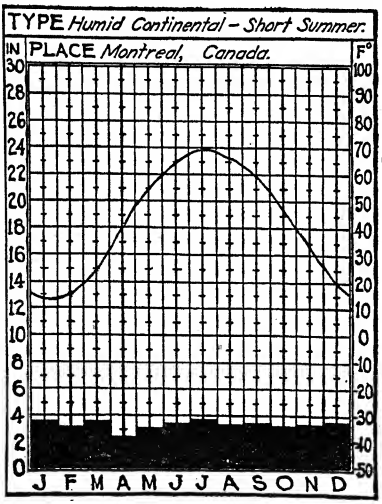

FIG. 107.—Average monthly temperature and precipitation at a station in the humid continental climate with short summers. The absence of a marked summer maximum in precipitation results from the very abundant winter snowfall.

Temperature. Warm to hot summers and cold winters are characteristic of the regions mentioned above. The annual range of temperature is, therefore, large (Fig. 107). The monsoon tendency, with southerly winds in summer and northerly winds in winter, tends to increase the extremes of temperature. In general, the severity of the climate increases from south to north and from coast to interior. Higher humidity along the Atlantic seaboard causes summer heat to be more oppressive and sultry and the winter cold more raw and penetrating than are the drier extremes of the interior. Temperature contrasts from south to north are much greater in winter than in summer. Between St. Louis and Winnipeg the January contrast amounts to 34°; in July it is only 13°.

Precipitation. In humid continental climates, the maximum precipitation usually occurs in the summer, although winters are not necessarily dry (Fig. 108). The summer maximum is due to

(1) the monsoonal tendency, as a result of which southerly winds blowing from sea to land carry great quantities of water vapor inland, (2) the resulting increased absolute humidity in summer, and (3) strong convection due to high temperatures. The warm-season rainfall is mainly convectional, a considerable percentage falling as the heavy downpours of thunderstorms. In winter, in addition to low absolute humidity, anticyclones with winds blowing from land to sea check the importation of water vapor from the ocean and sometimes retard the passage of lows across the continent.

The economic importance to agricultural production of having the year's rainfall relatively concentrated in the growing season cannot be overestimated. As these climates have a pronounced winter season, it is highly essential that periods of sufficient warmth and sufficient rainfall coincide. The great American Middle West is a highly productive agricultural region. This would not be the case if its rainfall were like that of southern California.

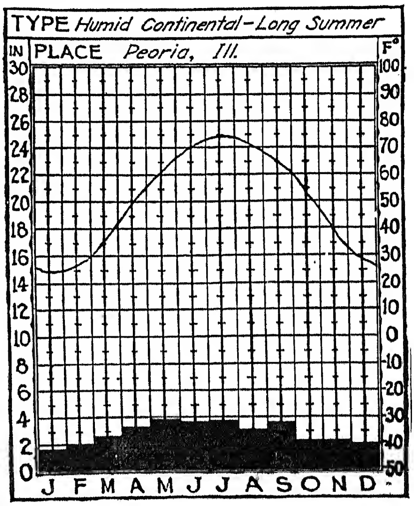

FIG. 108.—Average monthly temperature and precipitation for a representative humid continental climate with long summers.

Winters in humid continental climates are characterized by periods of cloudy, cyclonic weather. Precipitation may be in the form of rain or snow and occasionally sleet (Fig. 109). It takes 5 to 15 inches of snow to equal 1 inch of rain. A snow cover is of economic importance on fields planted to winter wheat, because (1) it adds moisture to the soil and, (2) owing to its low conductivity, it prevents the ground from becoming excessively cold. The snow, acting as a sort of blanket, helps to prevent winter freezing of the wheat.

Another effect of a snow cover is, of course, to reduce winter temperatures. The sun's heat is reflected from the white surface during daylight hours, whereas, in contrast, a field of black soil absorbs much heat. Night temperatures drop noticeably because

the snow has prevented the warming of the earth's surface during the day. In those parts of northeastern United States and Canada where winter cyclones are particularly numerous and well developed, such as the Upper Great Lakes Region, the St. Lawrence Valley, New England, and the Canadian maritime provinces, snow becomes excessively deep. Thus northern New York and parts of New England have more than 7 feet of snowfall during an average winter, and the snow cover remains on the ground for more than 4 months. In parts of the Adirondack Mountains 150 inches or more of snow falls annually. Over the American Great Plains, on the other hand, the fall of snow amounts to only 20 or 30 inches.

Seasonal Weather. In no other climate are rapid and irregular weather changes so characteristic as in the humid continental. These "spells of weather," caused by the passage of lows and highs, are numerous on marine west coasts, but in those locations temperature changes are not so severe. In eastern United States in particular, storm control is especially strong.

It is in the cold season, when storm tracks move south, that extreme weather changes occur. At that season sun control is much less dominant than that of moving cyclones and anticyclones. Changes in barometric pressure and wind velocity are greater than in summer. Daily temperatures often depend upon the direction of the wind. Thus a north wind one day with near zero weather may be followed next day by a south wind with temperatures 20° to 30° higher, and vice versa. Both lows and highs tend to move faster and to be larger, more frequent, and better developed in winter than at any other season. In the United States there is a distinct concentration of winter storm tracks over the Northeastern states, so it is this region which experiences the most frequent weather changes. In far continental interiors, strong highs tend to develop, causing steady cold weather and checking the activity of moving cyclones. Mixed with clear weather are periods of gray days with a stratus cloud covering from which little or no precipitation falls.

A blizzard is a severe winter storm which occurs in central North America and in Russia. It is not merely a heavy snow-

storm. It is a combination of strong winds, zero cold, and drifting, powdery snow. Actually, there may be no precipitation falling at the time, yet the air is filled to a height of several hundred feet by swirling masses of dry, finely pulverized snow, whipped up from the freshly fallen cover. Sometimes the sun can be seen shining wanly through the shroud of flakes. These storms are dangerous to both man and beast who may be caught long distances from shelter. On the weather map of the United States this type of storm is associated with a well-developed

FIG. 109.—Winter snow scene on a typical farm in the American corn belt.

low over the Central states followed by a high from western Canada and Montana. The bitter cold of the polar continental air mass in the high may be 20° to 40° below zero or even lower. The cold front advances over the country from west to east, the strong northwest winds often reaching the Gulf states. More frequent and widespread is the cold wave of winter in the United States. The temperature usually drops some 20° in 24 hours and remains near zero for several days. The sharp drop in temperature, which is the cold wave, occurs when the wind shifts from an easterly direction to the northwest.

Summer weather is dominantly under the influence of the sun. Storm tracks move northward. Weather is more uniform from day to day than in winter. Temperatures are much the

same over wide areas. Cyclones and anticyclones are weaker and less frequent. Clear, windy days are followed by hot, stagnant nights. On days of weaker winds and higher humidity, heat thunderstorms may develop during the warmer hours. Hot waves result from southerly winds combined with high sun and clear skies which drive midday temperatures to 100° or above over vast areas. Such conditions are brought about by a stagnant high in the south and a slow-moving, weak low, with little cloudiness, to the north. Anticyclones with cool, northerly winds are indeed welcome following such trying periods of blistering heat. Long, hot spells of summer weather without rain constitute the dreaded drought of central and eastern United States. The damage done by these dry periods to agricultural crops and livestock may run into millions of dollars.

Spring and autumn are transition seasons. Spring especially is noted for "fickle" weather. It is the season when the sun is trying to reestablish its control over cyclones, and the struggle results in sharp and peculiar changes in weather. In February or March, owing to abnormally warm weather, the buds of fruit trees may swell and then be killed by a later period of freezing temperatures. Autumn witnesses some of the loveliest days of the year but likewise some of the rawest, gloomiest weather. A temporary return of warm, sunny days with cool nights in October and early November brings the much cherished Indian Summer.

Humid continental climate is divided into two subtypes: long-summer subtype and short-summer subtype.

Long-summer Subtype. This long-summer phase (Fig. 108) is sometimes called *corn-belt climate*, because much of the world's commercial corn crop is grown in regions having its imprint. It is also called the *oak-maple-hickory climate*, because such trees dominate the hardwood forests found over much of these areas. In the United States this subtype covers a tier of states from central Kansas and Nebraska to the Atlantic Coast, including, in addition to the two states mentioned, Iowa, Missouri, Illinois, southern Wisconsin and Michigan, Indiana, Ohio, Pennsylvania, southern New York, and the coast states from southern New England to about Maryland. The American corn belt lies within its borders. In Europe this climate prevails only in the south-

central portions of the continent: the Danube and Balkan States and the Po Valley of Italy. It is on the plains of the Danube and in the Po Valley that much of Europe's corn crop is grown. The third principal region is in eastern Asia, including northern China, southern Manchuria, most of Chosen, and northern Japan. In this Asiatic area, monsoon winds and rainfall are particularly well developed.

Since these regions occupy the southern portions of the areas having humid continental climate, they experience a relatively long growing season of 5 to 7 months and only moderately severe winters. At St. Louis, Mo., the thermometer seldom records zero. Summers are likely to be hot and humid, resembling very much the tropical rainforest climate of the Amazon Valley. Because the wind dies with the sunset, nights tend to be warm and humid, making sleep indoors a difficult matter. In the crowded tenement districts of large cities, people abandon the hot, sultry air inside their homes and seek the open parks, where they spend the night. This is the season during which many inhabitants enjoy their vacations in the north woods or on the cool slopes of the Rocky Mountains.

CLIMATIC DATA—LONG-SUMMER SUBTYPE

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
						Peoria, Ill.								
Temp.	24	28	40	51	62	71	75	73	65	53	39	28	50.8	51.6
Precip.	1.8	2.0	2.7	3.3	3.9	3.8	3.8	3.2	3.8	2.4	2.4	2.0	34.9	
						New York City								
Temp.	31	31	39	49	60	69	74	72	67	56	44	34	52.1	43.0
Precip.	3.3	3.3	3.4	3.3	3.4	3.4	4.1	4.3	3.4	3.4	3.4	3.3	42.0	
						Bucureşti (Bucharest), Rumania								
Temp.	26	29	40	52	61	68	73	71	64	54	41	30	50.7	47.5
Precip.	1.2	1.1	1.7	2.0	2.5	3.3	2.8	1.9	1.5	1.5	1.9	1.7	23.0	
						Peiping, China								
Temp.	24	29	41	57	68	76	79	77	68	55	39	27	53	55
Precip.	0.1	0.2	0.2	0.6	1.4	3.0	9.4	6.3	2.6	0.6	0.3	0.1	24.9	

Short-summer Subtype. This more severe phase of humid continental climate lies north of the long-summer subtype and between it and subarctic climate. It is sometimes referred to as the *spring-wheat* type, because of the prevalence of this cereal in certain areas (Fig. 110). In North America this climate extends from southern Alberta, North Dakota, and Minnesota eastward to the Atlantic. In Eurasia it includes most of Poland,

eastern Germany, the small Baltic States, and a large part of the central Russian Plain between 50° and 60° of latitude. A

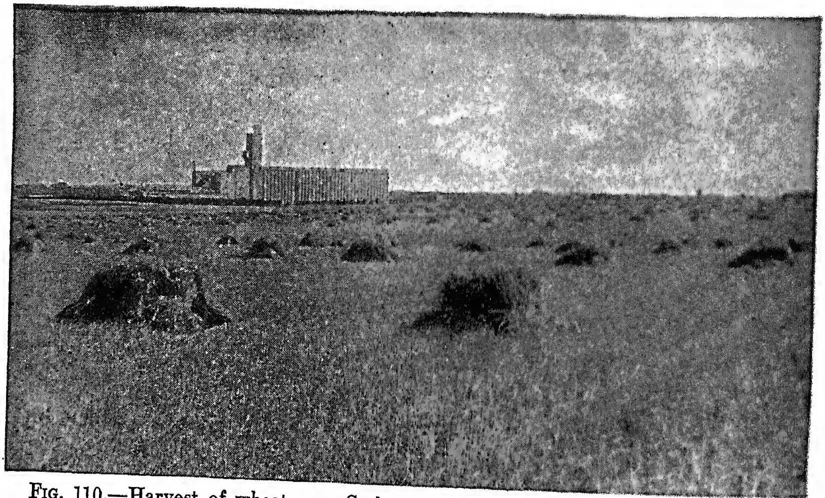

FIG. 110.—Harvest of wheat near Saskatoon, Sask., Canada. This was planted in the spring. Winter wheat, in localities such as Kansas, Missouri, and Illinois, is planted in early autumn.

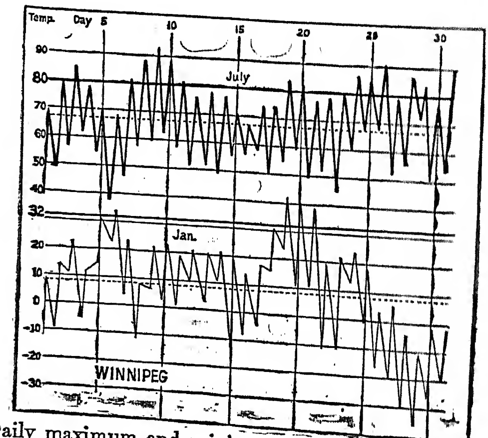

FIG. 111.—Daily maximum and minimum temperatures for the extreme months at a representative station in humid continental climate with short summers. (*Courtesy of Mark Jefferson and Geographical Review.*)

third area appears in northern Manchuria and southeastern Siberia.

Summers are usually warm for a few months, but the climate is handicapped by the short duration of the growing season of

3 to 5 months. Long summer days of these high latitudes somewhat offset this disadvantage. The cooler summer weather of these regions is an asset in one respect, *viz.*, in that it attracts thousands of tourists from more southerly localities. The long winter is the dominant season. In January and February, temperatures hover in the neighborhood of zero much of the time. At Winnipeg in January, daily maximum temperatures average 6°, and minimum temperatures −14° (Fig. 111). Annual precipitation in these regions is usually less than in the long-summer subtype, owing partly to greater distance from the sea. Because of continuous low winter temperatures, the snow cover remains on the ground for long periods of time.

CLIMATIC DATA—SHORT-SUMMER SUBTYPE

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
						Madison, Wis.								
Temp.	17	20	31	46	58	67	72	70	62	50	35	23	45.8	55.5
Precip.	1.5	1.5	2.1	2.6	3.7	3.9	3.8	3.2	3.6	2.4	1.8	1.6	31.6	
						Moskva (Moscow), U.S.S.R.								
Temp.	12	15	23	38	53	62	66	33	52	40	28	17	39.0	53.8
Precip.	1.1	1.0	1.2	1.5	1.9	2.0	2.8	2.9	2.2	1.4	1.6	1.5	21.1	
						Harbin, Manchuria								
Temp.	−2	5	24	42	56	66	72	69	58	40	21	3	37.9	73.8
Precip.	0.1	0.2	0.4	0.9	1.7	3.8	4.5	4.1	1.8	1.3	0.3	0.2	19.3	

Productivity of Humid Continental Climate. This climate at present is one of the greatest producing climates of the earth. The original natural vegetation consisted mainly of a mixture of tall-grass prairie and deciduous woodlands. Tree growth was more pronounced in the more humid areas and along streams. In the virgin state, the prairies provided some of the finest natural grazing lands on the earth. Most of the grasslands, however, have long been under cultivation, because they are excellent producers of field crops, especially the cereals, such as corn, wheat, oats, barley, and rye. The production of corn, together with certain hay and forage crops, early encouraged the fattening of livestock, which in turn brought into existence the huge meat-packing industry.

Formerly, excellent forests existed in this type of climate in both Europe and North America. The northern part of the central hardwood-forest belt of the United States lies in the long-summer subtype of this climate. Oak, maple, hickory, and

birch are a few of the abundant and valuable deciduous trees of this belt, which extends from western Missouri northeastward to Pennsylvania. Large parts of this forest were destroyed in the process of early settlement of the Central states. Excellent forests of Norway pine, white pine, spruce, fir, hemlock, and other trees originally extended from New England to Minnesota. Lumber companies early attacked these fine forests, the cutting gradually advancing from east to west. The remaining stand of pine in Michigan, Wisconsin, and Minnesota today is less than 2 per cent of the original extent. In the Lake states alone there are 25 to 30 million acres of cut-over country, much of it of little value except as potential forest or resort land.

Some of the richest soils in the world are found in regions of humid continental climate. These excellent soils have resulted largely from the annual growth and decay of grasses over a long period of time. In general, grassland soils are richer than those of forested areas. Probably the richest soils in North America are found in the so-called *black-earth belt* which occupies the tier of states from North Dakota to Texas. Similar soils are found in parts of Russia, especially in the region north of the Black Sea. More noticeably in the northerly portions of this climatic type, the soils show the effects of the great continental glaciers which moved southward from certain northern parts of Europe and North America.

Subarctic Climates

General Features and Location. Subarctic is the extreme in continental climates, having the largest annual range of temperature on the earth. It is found only in the northern parts of North America and Eurasia, largely because of the fact that these great landmasses undergo greater changes in temperature with the change of seasons than do large water bodies at similar latitudes. The poleward boundary of subarctic climate is approximately the isotherm of 50° for the warmest month (usually July), which closely coincides with the northern limit of tree growth. Beyond this isotherm, in the tundra, lowly vegetation forms such as mosses, lichens, and bushes predominate. To the subarctic lands of Eurasia, with their extensive coniferous forests, the Russians have given the name *taiga* (tī′-ga).

At Yakutsk, Siberia, nearly 62°N., representing the extreme in subarctic climate, the warmest month, July, has an average temperature of 66° which is higher than the same month at Berlin, London, or San Francisco. Midday temperatures often reach 80° to 90°. This is due largely to the long summer days, long twilight, and very short period of real darkness. For example, at latitude 55°N., June days average 17 hours of possible sunshine; and at 65°N., 22 hours. In the more northerly portions of the subarctic lands at the time of the summer solstice, one can read a paper out-of-doors even at midnight.

Winter follows rapidly on the heels of summer, so that the length of the growing season is only 50 to 75 days. Even in July and August, freezing temperatures sometimes occur. A shift of the wind to the north brings with it the chill of the ice-laden arctic. Such conditions are serious handicaps to agricultural development and have contributed largely to slow permanent settlement within subarctic regions.

Siberia holds the record for low temperatures at low elevations. Verkhoyansk, in the northeastern part, boasts an average January temperature of −59°, with an absolute minimum of −90° recorded in February, 1892. This, of course, is an extreme case. At Yakutsk, where July averages 66°, January averages −46°, making an annual range of 112°. Concerning the Siberian winter, Hann writes:

> It is not possible to describe the terrible cold one has to endure; one has to experience it to appreciate it. The quicksilver (mercury) freezes solid and can be cut and hammered like lead; iron becomes brittle, and the hatchet breaks like glass; wood, depending upon the degree of moisture in it, becomes harder than iron and withstands the axe so that only completely dry wood can be split.

Winter weather in similar latitudes of North America, however, is not quite so severe as that of Siberia.

Subarctic Eurasia and North America are largely covered by taiga, softwood forests which rank among the most extensive and least known wildernesses of the earth (Fig. 112). Conifers, mainly spruce, fir, larch, and pine, occupy in the neighborhood of 75 per cent of the area. Although the extent of these forests is very great, their economic value is not to be overemphasized.

Trees are not closely spaced, and even in the southern portions of the region their diameters rarely exceed $1\frac{1}{4}$ feet. These forests are the home of many of the earth's most important

FIG. 112.—Taiga in the ice-scoured region of Canada. The meager soil cover permits only a thin stand of trees. (*Courtesy of Royal Canadian Air Force.*)

fur-bearing animals, many of which are being killed at an alarming rate. In general, the subarctic is a region of inferior soils, because the long, cold winters retard many of the processes of soil formation.

CLIMATIC DATA—SUBARCTIC CLIMATE

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Yr.*	*Range*
						Fort Vermilion, Alberta, Canada								
Temp.	−14	−6	8	30	47	55	60	57	46	32	10	− 4	26.7	74.3
Precip.	0.6	0.3	0.5	0.7	1.0	1.9	2.1	2.1	1.4	0.7	0.5	0.4	12.3	
						Moose Factory, Ontario, Canada								
Temp.	−4	−2	10	28	42	54	61	59	51	39	22	5	30.4	65.6
Precip.	1.3	0.9	1.1	1.0	1.8	2.2	2.4	3.3	2.9	1.8	1.1	1.1	21.0	
						Yakutsk, Siberia, U.S.S.R.								
Temp.	−46	−35	−10	16	41	59	66	60	42	16	−21	−41	12	112
Precip.	0.9	0.2	0.4	0.6	1.1	2.1	1.7	2.6	1.2	1.4	0.6	0.9	13.7	

Tundra Climate

Location. The most extensive tundra areas are the Arctic Sea margins of North America and Eurasia. Most of the islands north of Canada and the coastal fringe of southern Greenland are likewise included. There is very little tundra in the Southern Hemisphere.

Long, bitterly cold winters and very short, cool summers are the rule (Fig. 113). Along the arctic coasts of Siberia, *average* January and February temperatures are in the neighborhood of —35° or —40°. Winter temperatures are not so severe along the northern coast of North America. Raw and chilly, the warmest months of the tundra, which average around 35° to 45°, resemble March and April in midwestern United States. Usually only 2 to 4 months have average temperatures above freezing, and killing frost is likely to occur at any time. Because of the unusually long, cold season, the subsoil is permanently frozen. Fog sometimes lasts for days at a time. The snow cover begins to disappear in May, and the lakes are usually rid of their ice cover in June. Bog- and swampland dominate the landscape. Myriads of mosquitoes and black flies make life almost unbearable for man and beast alike during the summer period of wet earth. Precipitation is not over 10 or 12 inches for the year and shows a summer maximum.

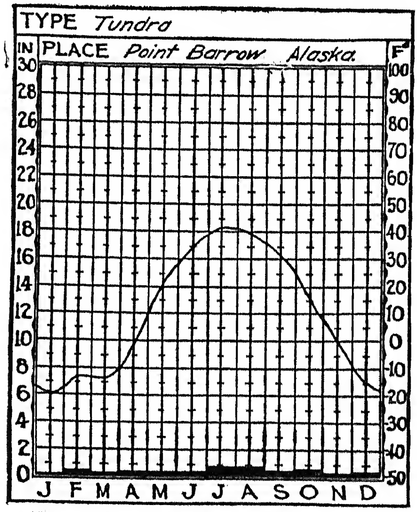

Fig. 113.—Average monthly temperatures and precipitation for a representative tundra station.

The reindeer, or caribou, is to the arctic tundra what the camel is to the tropical desert. These animals, together with the musk ox, feed upon certain forms of native vegetation which consists of mosses, lichens, sedges, and in some localities flowering and bushy plants, together with stunted birches, willow, and aspen. For the arctic peoples, the reindeer provides food, cloth-

ing, transportation, and shelter. The herds, sometimes numbering several hundred, are migratory, covering extensive areas in their search for food. Eskimos, who inhabit the coasts of tundra lands and who live mainly upon sea foods, are being taught to tend reindeer herds in parts of Alaska. Some of the reindeer meat is exported to Pacific Coast ports of the United States.

Ice-cap Climate

General Features and Location. This is the least known of the world's climatic types. It is found over the permanent continental ice sheets of Antarctica and Greenland and over the frozen ocean in the vicinity of the North Pole. Only limited climatic data are available from these deserts of snow and ice where the average temperature of no month is above 32°. The average temperature of an entire year in the tropical rainforest is 75° to 80°, but that of the interior of the Greenland ice cap is estimated at −25° and at the South Pole probably colder. December and January, two of the warmest months at the South Pole, have been found to have averages of about −10°.

Precipitation is meager and almost entirely in the form of snow, much of which consists of dry, sandlike particles. Expeditions of Admiral Richard E. Byrd into the antarctic have shown that this region has the coldest warm season on earth. Especially toward the edges of Antarctica, severe blizzards with winds having velocities of 50 to 75 miles per hour are features of the climate that mean death to any man or animal not adequately protected.

Mountain Climates

General Features and Location. Almost endless varieties of local climates exist within a mountain mass. Atmospheric conditions differ with altitude and exposure and, of course, with latitude. It cannot be said that there is a definite mountain type of climate.

A notable characteristic of high-altitude climate is the intensity of insolation. This is largely due to the cleaner, drier, and thinner air. The great relative intensity of the sun's rays

attracts the attention of nearly all persons going to high elevations. Insolation is not only more intense, but it is also richer in the shorter wave lengths of energy, the violet and ultraviolet rays. One therefore burns and tans quickly in the mountains. Because of the brilliant sunshine and pure air, many sanitariums are established at high elevations. Temperature decreases with altitude on the average about 3° per 1,000 feet. Climatically, this decrease is of great importance in tropical lands. Quito, Ecuador, on the equator, at an elevation of 9,350 feet, has an average annual temperature of 54°, which is 25° lower than that of the adjacent Amazon lowland. Mexico City, with an elevation of 7,400 feet and situated about 4° south of the Tropic of Cancer, has an average January temperature of 54° and a July average of 62°. White people in the tropics seek high elevations where cool and uniform temperatures are to be found. Mountain climate is similar to that of the California coast in this respect—in the sun, one feels warm; in the shade, cool. During the day, owing to convection, a warm wind blows up a mountain valley; at night, a cool wind descends from higher elevations. Cool evening breezes and low humidity are the principal climatic assets of the many summer resorts of the Colorado Rockies.

Winds that ascend mountain slopes are cooled by expansion. Condensation of water vapor results in the formation, especially during midday, of huge cumulus and cumulo-nimbus clouds. Precipitation in the mountains of arid lands creates "islands" of vegetation. Where a mountain system lies at right angles to the prevailing wind, the windward slopes are likely to receive frequent rains. Opposite the wet side is the rain shadow. The abundant precipitation in mountains is of much importance. It furnishes a source of water for springs, rivers, irrigation, and artesian wells. It is responsible for the existence of many excellent forests and grazing lands. Occasionally, terrific downpours may result in floods. Glaciers and snow, especially in the Alps, are scenic attractions of many summer resorts.

Summary

In this chapter and the preceding one we have learned that there are many types of climate on the earth's surface. These climates may be classified as follows:

The low-latitude, or tropical, climates are of three types:

1. Tropical rainforest:
    a. Windward coasts.
    b. Monsoon variety.
2. Tropical savanna.
3. Low-latitude dry climate:
    a. Deserts.
    b. Steppes.

The climates of the middle latitudes or intermediate zones, are also of three types:

1. Middle-latitude dry climates:
    a. Deserts.
    b. Steppes.
2. Warm, humid climates:
    a. Mediterranean.
    b. Wet subtropical.
    c. Marine west coasts.
3. Cold, humid climates:
    a. Humid continental (long summer and short summer).
    b. Subarctic.

The high latitudes, or polar caps, are the regions where the two types of polar climates prevail:

1. Tundra.
2. Ice cap.

Our study so far has been concerned mainly with the atmosphere—temperature, pressure, wind belts, precipitation, storms, and climate. Precipitation causes rivers to form. Abundant snowfall, especially in mountains, may cause glaciers to form. Rivers and glaciers, together with wind-blown sand, carve many of the features of the earth's surface. Our study, therefore, shifts now to the solid earth's crust, or lithosphere, and considers, first, its composition and, second, how its surface features are made.

Questions

MEDITERRANEAN CLIMATE

1. What are the three principal features of this climate?
2. Regions in this climate are alternately influenced by what wind belts?

3. Name the five major regions having this climate.

4. Contrast the temperatures of San Francisco and Red Bluff. Explain.

5. Why is this climate famed for its winter weather?

6. What is the outstanding characteristic of the Mediterranean type of rainfall?

7. Why is rainfall heavier at San Francisco than at San Diego?

8. Why are thunderstorms rare in southern California?

9. When are grains harvested in regions of Mediterranean climate?

10. Explain the cause and effects of a sirocco.

11. Describe the vegetation typical of this climate. What is chaparral?

12. Where is the cork oak found? Why does this tree produce a thick bark?

13. Why has fruit drying become an important industry in the vicinity of Fresno, Calif.?

HUMID SUBTROPICAL CLIMATE

14. In what three respects does this climate differ from Mediterranean climate?

15. Why does the size of a continent influence the monsoon tendency?

16. Locate the three larger regions having humid subtropical climate.

17. What is the average length of the growing season in regions having this climate?

18. Compare "sensible" temperatures in Florida and California.

19. Why are cold waves more severe in the Gulf states than in southeastern China?

20. Where do hurricanes and typhoons occur? When?

21. Contrast summer and winter rainfall.

22. Why is the humid subtropical climate the most productive climate of middle latitudes?

23. Discuss native vegetation in this type of climate.

24. What agricultural crops are produced in this climate?

MARINE WEST-COAST CLIMATE

25. Why are marine climates located on west coasts? At what latitudes?

26. Locate the principal world regions having marine climate.

27. Why does this climate penetrate farther inland in Europe than in North America?

28. Discuss summer and winter temperatures. How long is the growing season?

29. What are the two outstanding characteristics of marine rainfall?

30. Contrast snowfalls in western Europe and the Cascades.

31. What is the nature of rainfall?

32. How do these regions rank in cloudiness?

33. Where are the finest forests in the United States? What trees predominate?

34. Why are some regions in this climate noted for livestock production?

HUMID CONTINENTAL CLIMATE

35. Name and locate the world regions having this climate.

36. Why is the annual range of temperature large?

37. Summer maximum in rainfall is due to what three causes?

38. Why is maximum summer rainfall of great economic importance?

39. What is the value of snow on winter wheat land?

40. Why are weather changes rapid and irregular? Why more so in winter?

41. Where is snowfall heavier, in Kansas or in New England? Why?

42. Discuss the blizzard. The cold wave.

43. What causes a hot wave? A drought?

44. Why is spring a season of fickle weather? What is Indian Summer?

45. Name the states in the long-summer subtype. What cereal is typical of this climate? What trees? What is the chief objection to the summer climate?

46. What regions have the short-summer type of climate? What cereal is important in some of those areas?

47. In the short-summer subtype, what is the length of the growing season?

48. In what respect are cool summers of northern Minnesota and Wisconsin an asset?

49. What cereals are produced in humid continental climate?

50. What are deciduous trees? Conifers? Name several species of each. Where are they found in humid continental climate? Which are hardwood?

SUBARCTIC CLIMATE

51. In what two ways is the poleward boundary determined?
52. Why is the July average at Yakutsk more than that of San Francisco?
53. How many possible hours of sunlight are there at the time of summer solstice at 55°N.? 65°N.?
54. What is the lowest temperature ever recorded at Verkhoyansk?
55. Discuss the forests and soils of this climate.

TUNDRA CLIMATE

56. Locate the principal tundra regions.
57. Describe the climate and vegetation of the tundra.
58. In what ways is the reindeer of value to the inhabitants of these regions?

ICE-CAP CLIMATE

59. Where are the two principal regions having this climate? Describe the temperature conditions.

MOUNTAIN CLIMATE

60. What are two characteristics of insolation in mountains?
61. Why are many cities located at high elevations in the tropics? Give examples.
62. What are the two principal climatic assets of the Colorado Rockies?
63. What type of clouds is common in summer in many mountains? At what time of day? Why? What is the rain shadow? Give an example.
64. In what ways is the abundant precipitation in mountains of much importance?

Suggested Activities

1. Study three maps of the world, one showing annual rainfall, another the types of climate, and a third the density of population. Suggest as many relationships as possible, learned from the study of these three maps.
2. Chicago and Rome are in about the same latitude. Contrast the climates of the two cities.
3. On a large wall outline map of North America, color the climatic regions. Paste or pin labels on the map showing economic products of the different regions.

4. Outline on a map the spring- and winter-wheat regions of North America. Contrast the two regions climatically.

5. Compare the climate of Fairbanks, Alaska, with that of Bergen, Norway. They are not greatly different in latitude.

6. Choose a definite location in the regions discussed in this chapter, and write a short paper on why you would prefer to live in that particular place.

NOTE: Other activities may be found in the laboratory manual.

TOPICS FOR CLASS REPORTS

1. Economic Products of Mediterranean Countries
2. Climatic Contrasts within the State of California
3. Florida versus California as a Winter Resort State
4. Citrus-fruit Production in the Gulf States
5. The Climate of India
6. Great Deserts of the World
7. A Comparison of the Climates of Seattle and New York
8. The Pacific Coast Forests of the United States
9. The Climate of Spring- and Winter-wheat Regions

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Chapter VIII. Weather Information for Pilots

International Weather Cooperation during Peace. In time of peace the meteorological services, or weather bureaus, of nations cooperate in exchanging meteorological reports, forecasts, and other weather information. In this way it is possible to keep track of storms and other weather conditions, which in general move across the earth from west to east. The powerful navy radio stations NAA and NSS, located at Annapolis and San Francisco, transmit long, detailed, short-wave weather broadcasts twice daily. Among the information contained in these broadcasts are (1) reports from a long list of weather stations in North America, (2) weather reports from ships and islands in both the Atlantic and Pacific Oceans, and (3) forecasts and weather summaries prepared by the U.S. Weather Bureau. The weather reports that are broadcast include those from several stations in eastern Canada, Greenland, and Iceland. European nations are interested in those broadcasts, which make it possible for them to plan and carry out more intelligently activities that are affected by the weather. Meteorologists in foreign countries and many sea captains construct daily weather maps from the reports broadcast. These maps show a picture of present weather conditions, and they indicate the likely weather changes.

U.S. Peacetime Aviation Weather Service. In our country many Civil Aeronautics Administration communication stations broadcast weather reports and forecasts at hourly intervals, or oftener. Pilots in flight may make contact with these stations at any time for information. At Weather Bureau airport stations weather charts and reports may be examined. Forecasters and other personnel on duty are available for detailed discussion of weather conditions.

War Stops International Weather Service. The mentioned broadcasts by NAA and NSS are not made in time of war. To do so would mean that friend and foe alike would be able to receive the information. Further, ships at sea do not send radio reports of their weather observations, because such reports would reveal the weather conditions, as well as their whereabouts, to the enemy. A report, to be worth anything, must include a ship's position in terms of latitude and longitude. In time of war, control of such localities as Greenland and Iceland is desired partly because of the importance of weather information, which can of course be very helpful to those who are able to obtain this data.

War Weather Service for Aviation in the United States. The Weather Bureau is as important in war as in peace, but its services cannot be made fully available to the public during war. This is necessary in order to keep the information out of the hands of the enemy. Broadcasts for aviation and other activities are modified, and a different type of service is made available at weather offices. Therefore pilots and others may obtain needed information, but the Weather Bureau avoids revealing the type of weather data that would be useful to the enemy.

The Descriptions in This Chapter. The weather services described in this chapter are those that are available to any person during times of peace, but they are for the most part greatly modified during time of war. The reading of teletype weather reports and weather maps is covered in detail. The pilot should learn these things if he expects to get the maximum amount of information that can be had at an airport weather office.

Information Sources

The three principal sources of weather information available to the pilot are (1) the services of the U.S. Weather Bureau; (2) the weather staffs of commercial air lines, and other private meteorologists; (3) the pilot's own observations, and deductions based on his training and experience.

U.S. Weather Bureau

The Weather Bureau has kept abreast with the development of aviation and is alert to the pilot's need for weather informa-

tion. It has given much attention to ways and means of furnishing information for both local and cross-country flying.

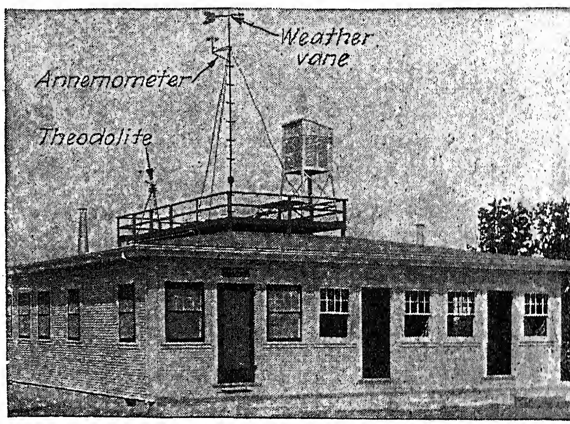
Development of the Weather Bureau. Since 1940 the Weather Bureau has been a part of the Department of Commerce, but it was formerly in the Department of Agriculture. It was originally established to forecast storms on the Great Lakes so that shipping losses could be lessened. Its usefulness for other purposes was soon recognized. Summaries of its daily weather observations make it possible to learn about the climate in all parts of the country. Forecasts of coming weather conditions for about two days ahead are helpful to agriculture, industry, transportation, and many other activities. For many years the bureau has forecast the approach of storms, temperature changes, precipitation, and wind conditions.

Weather Information Needs of Aviation. The weather information that a pilot requires is much different from that needed in other activities. He is not primarily interested in what the weather will be tomorrow but is more concerned with the existing weather conditions in the area in which his flight will be made. Further, he wants to be fully informed about any weather changes that are expected before the completion of his flight. Mere predictions of temperature changes and precipitation possibilities are not sufficient for aviation. The pilot who makes a local flight for pleasure or training purposes needs to know the surface wind direction and velocity, and whether or not the wind is gusty, *i.e.*, fluctuating in velocity. This information is needed for landing and taking off. Other things of interest to him are the ceiling, which is the distance between the ground and the bases of clouds present; the possibility of the occurrence of fog; and the possibility of ice formation in his carburetor. The pilot who intends to make a cross-country flight is interested in those and many other things such as the wind direction and velocity at various flight levels; the likelihood of ice formation on his airplane; bumpiness, or turbulence of the air, which was formerly known as "air pockets"; and the possibility of thunderstorms.

Type of Forecasts for Aviation. Since it is not now practicable to predict for 2 days ahead such details as ceiling and visibility, forecasts for aviation are made for only 8 hours in advance. However, this shorter forecast period is sufficiently long

for aviation purposes, for long trips may be made before the end of 8 hours.

Weather Bureau Help to Aviation. To meet the special needs of aviation the Weather Bureau has established at airports a dense network of stations (Fig. 114). Stations located along the airways report the surface weather conditions each hour, whereas other stations make reports every 3 or 6 hours. Some of the stations have facilities for determining and reporting the wind direction and velocity at various flight levels. A smaller number



(*Courtesy of U.S. Weather Bureau.*)

FIG. 114.—Eighteen-foot wind vane and anemometer mounted on platform on roof of observatory, together with large-sized shelter on 5-foot steel support and theodolite for pilot-balloon observations.

have special equipment for determining the temperature, humidity, and pressure values in the atmosphere high above the earth. At all these stations the weather is constantly watched, and any important change in the weather is reported at once.

Meteorological help is available at a typical Weather Bureau airport station as follows:

1. State forecasts

2. Up-to-the-minute surface and upper-air reports from many stations within hundreds of miles

3. Surface and upper-air weather maps drawn locally every 6 hours are on display and may be studied

4. Forecasts in terms of flying conditions are on file for the region as a whole and for many important surrounding airports. Forecasts can be obtained for special trips

5. Trained bureau personnel are on duty day and night and are available for consultation and advice
6. Access to communication services

State Forecasts

This type of forecast is of interest to pilots from the standpoint of planning activities for the following day or two. Issued every 6 hours, they describe weather conditions that are expected to exist a day or so in advance. For example, let us suppose that a pilot plans to fly from St. Louis to Kansas City early on Thursday morning. By phoning the airport weather office on Wednesday he would receive the State forecast as follows:

> Missouri: strong winds tonight, diminishing Thursday forenoon; showers early tonight; some light snow south portion late tonight; somewhat colder late tonight and Thursday forenoon.

This forecast shows that favorable weather conditions on Thursday would be likely. If a small light plane is to be flown, the pilot would not leave until the wind decreased in velocity.

Hourly Surface Weather Reports

When Taken and How Reported. The hundreds of weather stations located on the civil airways record and report the weather conditions each hour. These reports are known as "sequence" reports because each station in a particular group, or circuit, follows another definite station when making its report. By means of a teletype system the reports are rapidly exchanged between stations. The weather conditions reported that are of interest to pilots are as follows: weather classification, type of report, time of report, ceiling, sky conditions, visibility, weather conditions, obstructions to vision, barometric pressure, temperature, dew point, surface wind direction and velocity, altimeter setting, remarks, and special data.

For purposes of brevity, all parts of a report are sent in terms of ciphers, symbols, or abbreviations. Elements always are transmitted in the same order so that any person after sufficient practice is able to decode reports. All pilots should learn to do so. Some representative reports are shown on page 213. Their mean-

ings are given on page 214. The reports consist of the following items:

Station Call Letters. Each station is represented by a group of two or three call letters. They are often the first two letters of the name of the station, the first and last letter, or the first letter and another significant letter. Pilots learn the call letters of stations in their localities quickly; others can be learned as needed. Call letters of some of the stations are as follows:

AZ	Albany, N.Y.	OL	Oklahoma City, Okla.
BJ	Buffalo, N.Y.	PH	Phoenix, Ariz.
JG	Burlington, Vt.	PT	Pittsburgh, Pa.
CO	Columbus, Ohio	PW	Portland, Me.
DV	Denver, Colo.	PD	Portland, Ore.
DT	Detroit, Mich.	RC	Rochester, N.Y.
EA	Elmira, N.Y.	SZ	Sacramento, Calif.
ID	Indianapolis, Ind.	LS	St. Louis, Mo.
HT	Hartford, Conn.	SL	Salt Lake City, Utah
KC	Kansas City, Mo.	SA	Seattle, Wash.
MP	Minneapolis, Minn.	ZD	Springfield, Ill.
NK	Newark, N.J.	SR	Syracuse, N.Y.

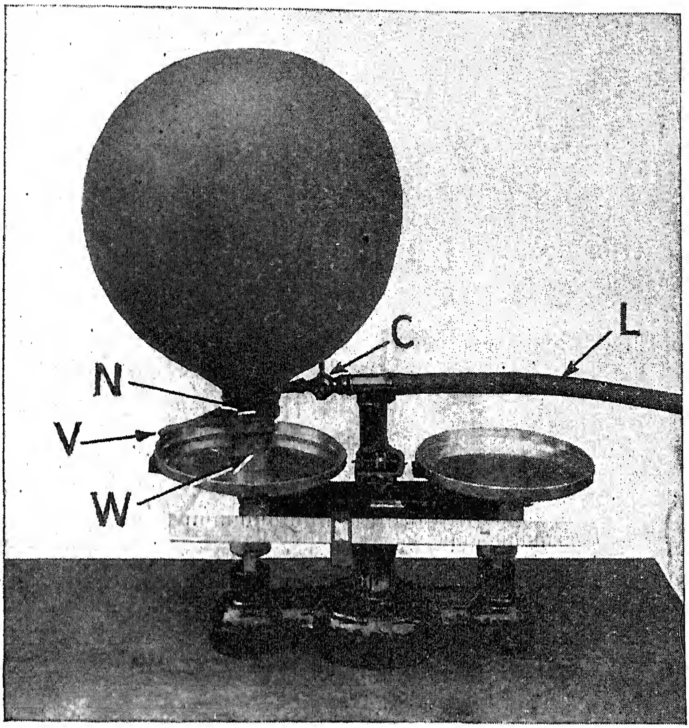
Classification of Report. The Civil Aeronautics Administration has established so-called *controlled zones* around certain important and busy airports. Special traffic rules based on weather conditions apply at those locations. Weather stations located within controlled zones classify their weather reports as X, N, or C. Ceiling and visibility conditions determine the weather classification. When the weather conditions are so poor as to be classified as X, landings and take-offs are not permitted. In N weather, flights are allowed, but the airplane must be equipped with "blind flying" instruments. Flight is not restricted in C, or contact, weather.

Type of Report. Most reports are the regular type that are sent in sequence each hour. When changes in the weather that are important to flying occur, a special report is made. A special report may also be transmitted at times between regular sequence reports, or it may be labeled "Spl" and sent with a regular sequence group.

Time of Report. The 24-hour clock is used to designate the time of a report or sequence of reports. The time zone is also shown. Examples are as follows:

0030C	12:30 A.M.	Central War Time
0357E	3:57 A.M.	Eastern War Time
1240M	12:40 P.M.	Mountain War Time
1830P	6:30 P.M.	Pacific War Time

It will be noticed that, if the time is given as 1300 or more, 12 is subtracted and the remainder is labeled P.M.



(*Courtesy of U.S. Weather Bureau.*)

FIG. 115.—Inflation balance used for "definite" inflation. (*C*) Three-way stopcock; (*L*) hydrogen line; (*N*) filler nozzle; (*V*) small rubber tube; (*W*) counterweight.

Ceiling. The ceiling is the first weather element reported. It is the distance between the ground and the base of the lowest cloud layer that covers more than one-half of the dome of the sky. The ceiling is reported in hundreds of feet, but if more than 10,000 feet it is known as "unlimited."

During the daytime, ceilings are determined by means of small rubber balloons known as ceiling balloons. They are inflated with just enough hydrogen or helium to give them an ascension

rate of about 400 feet per minute. By noting the elapsed time between the time of release and the time the balloon enters the cloud base, the ceiling is readily determined. Figure 115 shows a balloon being inflated. At night the ceiling is determined by directing toward the cloud a vertical beam of light which makes a

(*Courtesy of U.S. Weather Bureau.*)

FIG. 116.—Ceiling-light projector, complete with mounting.

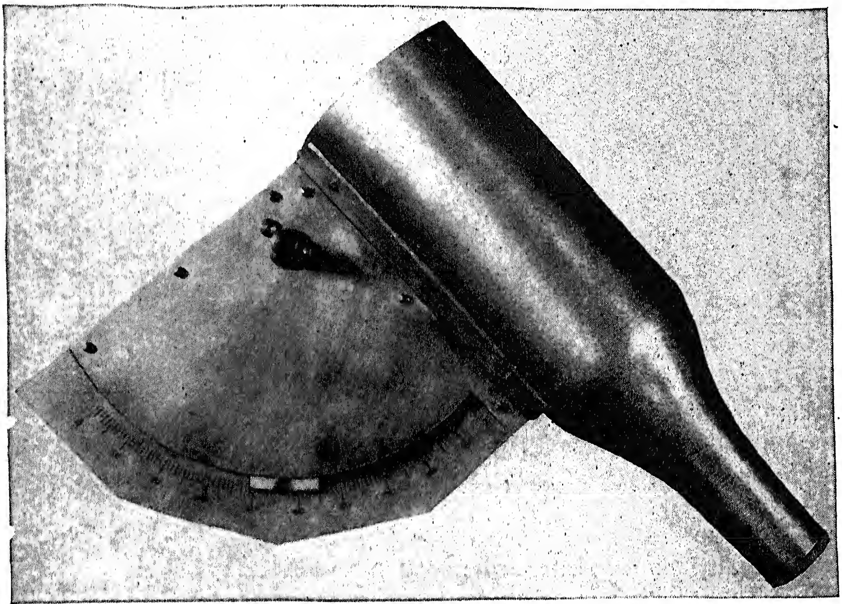
light spot on the cloud base. Figure 116 shows a ceiling light projector. The vertical angle of the spot is measured with a clinometer (Fig. 117). The ceiling value may then be found by multiplying the tangent of the vertical angle by the base line (distance of projector from the observer) (Fig. 118).

If measuring devices are not available, ceilings may be estimated. The various types of clouds are normally found within certain ranges of ceiling values. Therefore, the type of cloud

present suggests its height. Conversely, when ceiling values are known, the type of cloud present is indicated. Ceilings are reported as follows:

47	4,700 feet
0	50 feet or less
E15V	Estimated 1,500 feet and variable
Figure omitted	10,000 feet or more
+30	Greater than 3,000 feet; balloon blown out of sight

Sky Condition. Symbols are used to represent the portion of the sky that is covered with clouds. If the cloud layer is 10,000



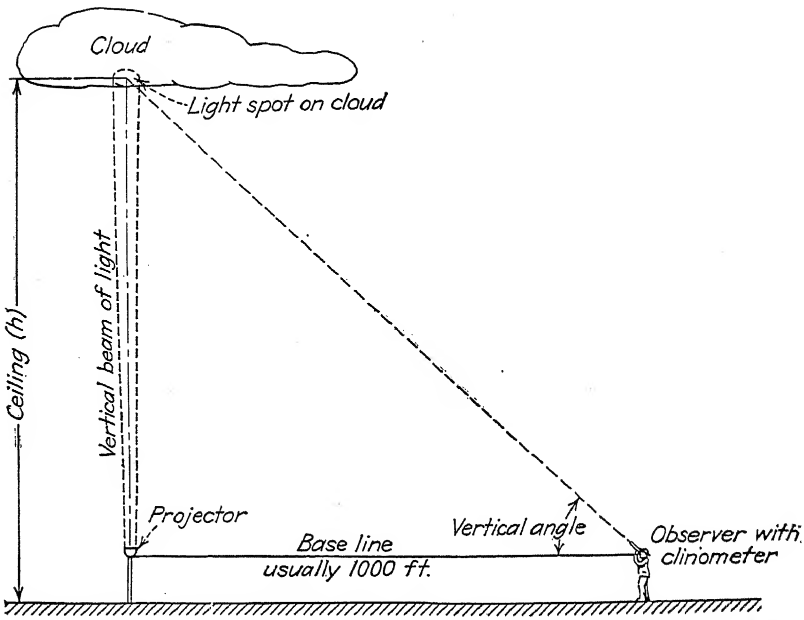
(Courtesy of U.S. Weather Bureau.)

FIG. 117.—Clinometer. An instrument designed for observing ceiling heights. Used to sight on the spot of light thrown against the cloud base by the ceiling light. From the angle indicated and a special table the cloud height is readily found. These heights are simply trigonometric computations, based on the known distance between the ceiling light and the clinometer, and the angular settings of these instruments.

feet or higher, the symbol is followed by a slanted line. Symbols and their meanings are as follows:

○ Clear (clouds cover less than one-tenth of the sky)
⦶ Scattered (clouds cover one-tenth to five-tenths of the sky)
⦷ Broken (clouds cover six-tenths to nine-tenths of the sky)
⊕ Overcast (clouds cover more than nine-tenths of the sky)

No symbol is used if the sky is obscured by dense fog or snow. Ceilings are unlimited when the sky condition is clear or



(*Courtesy of U.S. Weather Bureau.*)

FIG. 118.—Diagram showing relation of projector and angle-measuring device.

scattered. The estimated height of scattered clouds is shown by a figure preceding the scattered symbol. Examples are as follows:

⊕/30 ◐ High overcast, lower scattered at 3,000 feet
◍/70 ◐ High broken, lower scattered at 7,000 feet
−⊕/ High thin overcast (minus sign ahead of symbol indicates thin)
+◍ Dark lower broken (plus sign ahead of symbol indicates dark)

Visibility. With reference to weather reports, visibility is defined as the greatest distance, at the surface, which one may see large objects such as hills, buildings, and smokestacks. Unfortunately, visibility conditions may be entirely different at flight levels, but the reports are valuable as information for take-offs and landings. The visibility is shown in miles or fractions thereof. When it is 10 miles or more, the value is omitted. Values are recorded as follows:

6	6 miles
1/8	$\frac{1}{8}$ mile
2 1/2	$2\frac{1}{2}$ miles
Figure omitted	10 miles or greater
0	Visibility zero
1V	1 mile, variable

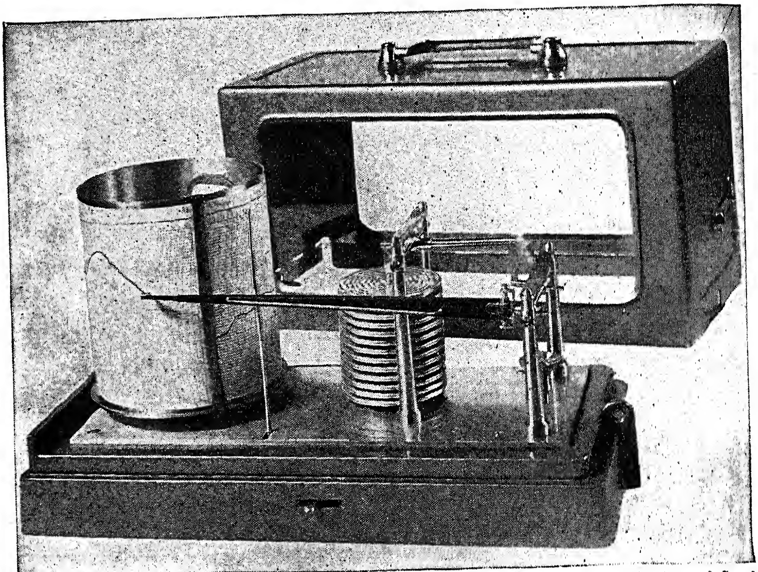
Weather. In weather reports, the term "weather" is applied to the occurrence of thunderstorms, tornadoes, and various forms of precipitation. Abbreviations are used, such as R for rain. The abbreviation is followed by + if of heavy intensity, − if of light; if the intensity is moderate, the symbol stands alone. The following are examples:

A	Hail
AP	Small hail
E	Sleet
L	Drizzle
R	Rain
RQ	Rain squall
RW	Rain showers
S	Snow
SP	Snow pellets
SQ	Snow squalls
SW	Snow showers
T	Thunderstorm
Tornado	Tornado (always spelled out)
ZL	Freezing drizzle
ZR	Freezing rain

Obstructions to Vision. By obstructions to vision is meant such phenomena as fog, smoke, and haze. These elements are represented by abbreviations, such as F for fog, K for smoke, and H for haze. The degree of visibility is determined largely by the presence or absence of precipitation and other obstructions to vision. It is therefore appropriate in a weather report that those symbols follow the visibility value. Obstruction to vision symbols are

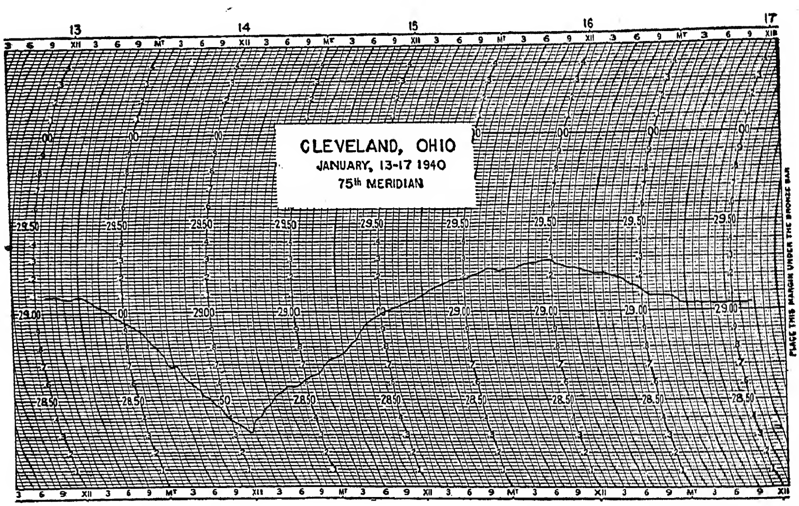
BD	Blowing dust
BN	Blowing sand
BS	Blowing snow
D	Dust
F	Fog
GF	Ground fog
GS	Drifting snow
H	Hazy
IF	Ice fog
K	Smoke

Barometric Pressure. The station barometric pressure, converted to sea level, is shown by three digits which represent tens, units, and tenths of millibars. Atmospheric pressure is determined chiefly by two factors, the elevation of the station above sea level and the existing weather conditions. In order to draw weather maps, station pressures are changed to the values they



(*Photograph by J. H. Schaefer and Son.*)

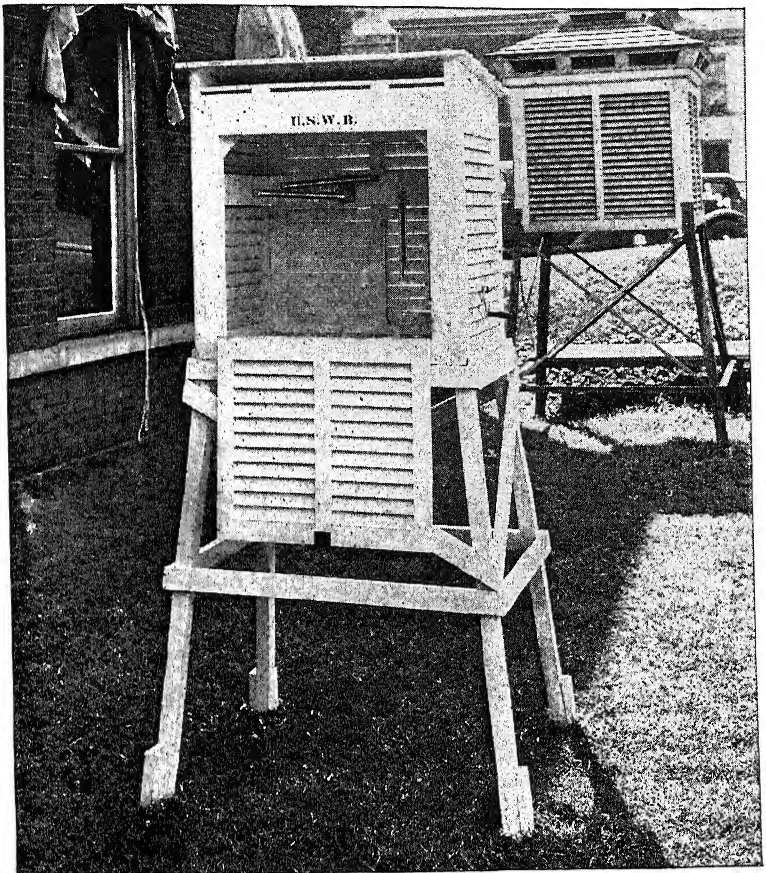
FIG. 119.—The barograph.



(*Courtesy of C.A.A.*)

FIG. 120.—Barograph trace.

would be if the station were located at sea level. Figure 119 shows a type of barograph used at airport weather stations.



(*Courtesy of U.S. Weather Bureau.*)

FIG. 121.—Cotton-region instrument shelter, door opened. Handle of psychrometer fan at right. (Large standard shelter on 5-foot steel support in background.)

Figure 120 shows a representative barograph trace. The following are typical pressure values as reported:

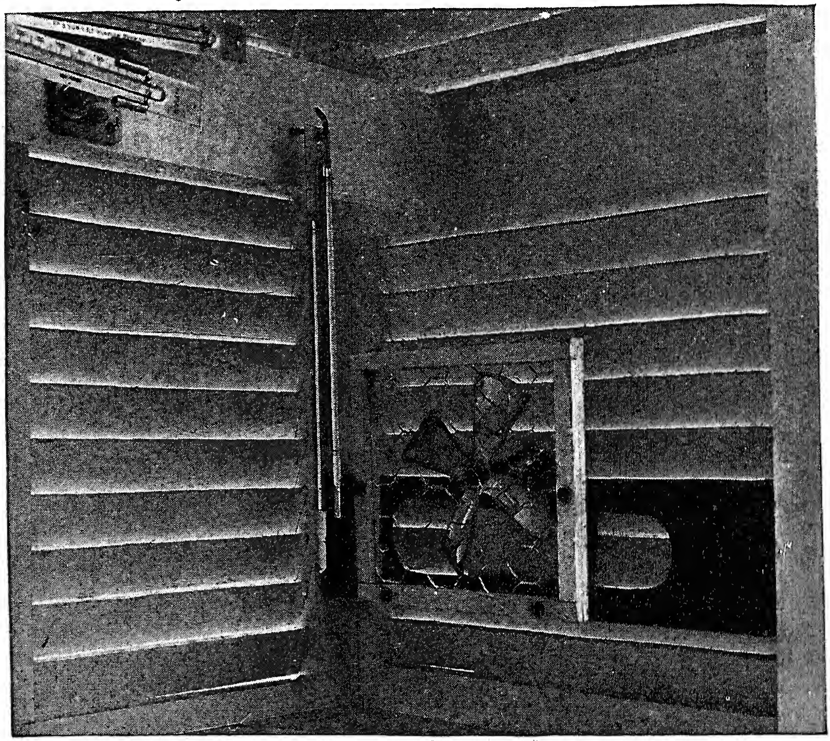
132	1013.2 millibars
224	1022.4 millibars
993	999.3 millibars

Temperature. The shade temperature of the air is shown in degrees Fahrenheit. In Figs. 121 and 122 are shown an instrument shelter, thermometers, and psychrometer fan.

Dew Point. The dew point is the temperature at which the air would be saturated with its existing water-vapor content. It is expressed in degrees Fahrenheit, and pilots watch its value very closely. Temperature and dew-point values are reported as follows:

60/59 temperature 60°, dew point 59°
5/−2 temperature 5°, dew point 2° below zero

Wind. The direction of the wind is reported to 16 points. Arrows that fly with the wind are used as symbols.



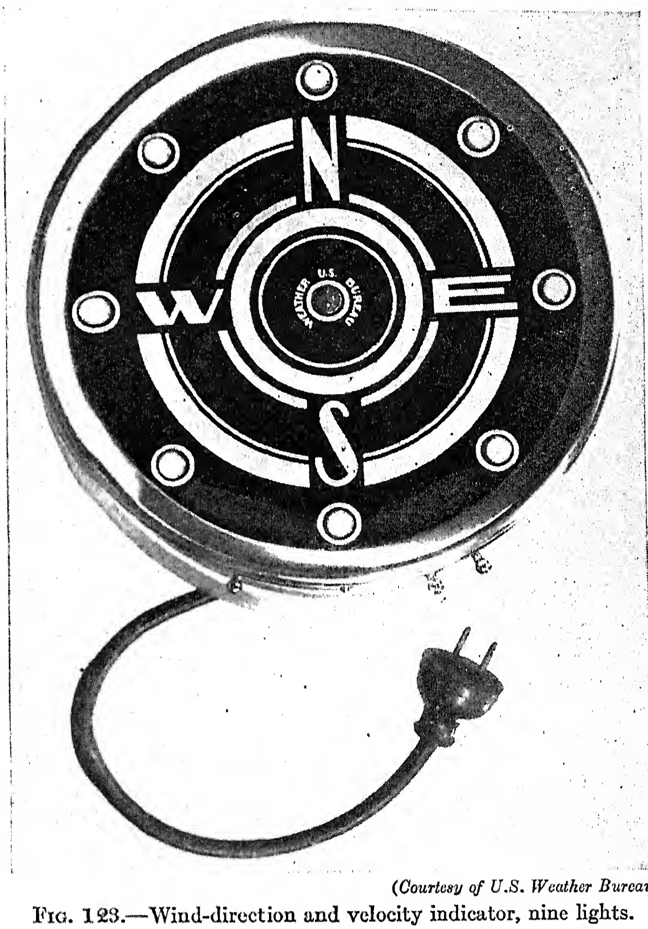
(*Courtesy of U.S. Weather Bureau.*)

FIG. 122.—View of right-hand of cotton-region shelter showing psychrometer fan and psychrometer.

Figure 123 shows a wind-direction and velocity indicator. The wind vane is wired to the wind direction and velocity indicator in such a way that the direction can be read to 16 points. For example, when the wind is from the west-northwest, both the west and northwest lights show.

At airports the wind velocity is measured with a special airway type three-cup anemometer. It is geared in such a way that

an electric circuit in the office is closed each time one-sixtieth of a mile of wind passes the instrument. The light in the center of the wind-direction and velocity indicator flashes on each time the anemometer circuit closes. A buzzer arrangement can also be switched in. By counting the number of flashes or buzzes for



(*Courtesy of U.S. Weather Bureau.*)

FIG. 123.—Wind-direction and velocity indicator, nine lights.

1 minute, the velocity of the wind is determined in miles per hour.

Gusty conditions are reported by placing minus or plus signs after the wind velocity. A minus sign indicates fresh gusts, and a plus sign means strong gusts.

One of the most useful parts of a report is that concerning the occurrence of a "wind shift." Wind shifts signify a change from

one type of weather to another. Also, it is in the vicinity of wind-shift areas that the poorest flying conditions occur. Therefore both the forecaster and the pilot are furnished valuable information when a wind shift is reported. The following are examples of wind reports:

↖	Wind blows from the southeast
↑	South wind
↑↖	South-southeast wind
→↗16	West-southwest, 16 miles per hour
↓14−	North, 14 miles per hour, fresh gusts
↗30E+	Southwest, 30 miles per hour, estimated, strong gusts
C	Calm (anemometer cups not turning)
↘13↗2152E−	Mild wind shift from southwest to northwest at 9:52 P.M. Eastern War Time; now 13 miles per hour.
→27↑2313C+	Severe wind shift from south to west at 11:13 P.M. Central War Time; now 27 miles per hour.

Altimeter Setting. The altimeter setting is expressed in inches and hundredths of inches of mercury. For brevity, the tens of inches are omitted in the report. The altimeter setting is a sea-level expression of the station pressure value. Prior to landings it is radioed to pilots so that their altimeters can be adjusted and will then read correctly while landing. When ceilings are low and visibility poor, it is essential that the altimeter register correctly. The following examples are typical altimeter settings as transmitted by teletype:

953	29.53 inches
978	29.78 inches
000	30.00 inches
022	30.22 inches

Remarks. Plain-language remarks in abbreviated form are reported in the cases of significant phenomena for which provision was not made in the report. Several types of remarks frequently used are:

⦶TPG MTNS	Clouds are topping the mountains
+⊕SW	Clouds are dark toward the southwest
2F NE	Fog bank to northeast, visibility in that direction is 2 miles

Special Data. Every 3 hours, pressure trends, cloud types, and other conditions are reported in numeral code. These data

are of interest to forecasters, and maps and forecasts are based on the values reported.

Hourly Sequence Reports

211535E
WJ C SPL 10⊕7⦶4F-H 156/51/47↑↖8/997/VSBY NE 6
UQ SPL 9⊕11/2RW-GF- 50/49↗3
NX E8⊕11/2R-F- 159/50/49↖6/999
TBM 00L-FF 149/46/46↑↖4/994
LG N 8⊕3RW-K- 152/52/48↖10/997
FB N 5⊕21/2F- 147/50/48↖8/995
TNV SPL 17⊕⦷7 163/50/46↖5/000/ ⦶ V⦷
HT C SPL E35⊕10⦶6R-F- 159/51/46↑7/999
PN E25⊕⦷8 50/47↗7
PR C-⊕/25⦶ 166/58/46↑↖10/001/BINOVC
BW C E40⦶⦷7 156/58/46↖8/998/RARAU
CN C SPL E15⊕5H 159/50/45→4/998/RARAU
PW C-⦶/30⦶ 156/58/45←↖6/998
AW C-⦷/30⦶ 156/58/43↑↗9/998
BB C-⦷/ 159/58/42↑19+/999
MT C ○ 149/58/40↑16/995

Special Observations

What They Are and How They Are Used. Occasionally a decided change in the weather occurs between the regularly scheduled times for hourly observations. A special observation is made and filed any time that a weather change might be of interest to a pilot or forecaster. They are immediately transmitted by teletype to other stations and broadcast to pilots in flight. Among conditions for which special observations are made are the following:

1. Changes in the weather which result in a changed classification (X, N, or C).
2. Beginning or ending of precipitation.
3. Change from rain to sleet or other types of precipitation.
4. Beginning or ending of hail.
5. Beginning or ending, or a change in intensity, of thunderstorms.
6. Certain changes in cloudiness and ceiling heights.
7. Beginning or ending of fog.
8. Certain changes in visibility.
9. Specified changes in wind direction or velocity.
10. A significant change in the altimeter setting.

TRANSLATION OF HOURLY

Station	*Classification*	*Type*	*Ceiling, Feet*	*Sky Condition*	*Visibility, Miles*	*Weather*
Westfield	Contact	Special	1,000	Overcast; lower scattered 700 feet	4	
Columbiaville	Not classified	Special	900	Overcast	1½	Light rain showers
New Hackensack	Not classified	Regular	Estimated 800	Overcast	1½	Light rain
Bear Mountain	Not classified	Regular	Zero	Not visible	Zero	Light drizzle
La Guardia Field	Instrument	Regular	800	Overcast	3	Light rain showers
Floyd Bennett Field	Instrument	Regular	500	Overcast	2½	
New Haven	Not classified	Special	1,700	Overcast; lower broken	7	
Hartford	Contact	Special	Estimated 3,500	Overcast; lower scattered 1,000 feet	6	Light rain
Putnam	Not classified	Regular	Estimated 2,500	Overcast; lower broken	8	
Providence	Contact	Regular	Unlimited	High thin overcast; lower scattered 2,500 feet	10 or more	
Boston	Contact	Regular	Estimated 4,000	Scattered; lower broken	7	
Concord	Contact	Special	Estimated 1,500	Overcast	5	
Portland	Contact	Regular	Unlimited	High thin scattered; lower scattered 3,000 feet	10 or more	
Augusta	Contact	Regular	Unlimited	High thin broken; lower scattered 3,000 feet	10 or more	
Bangor	Contact	Regular	Unlimited	High thin broken	10 or more	
Millinocket	Contact	Regular	Unlimited	Clear	10 or more	

SEQUENCE REPORTS

Obstructions to Vision	*Pressure, mb*	*Temperature*	*Dew Point*	*Wind Direction*	*Wind Velocity, mph*	*Altimeter Setting*	*Remarks*
Light fog; haze	1,015.6	51	47	S-SE	8	29.97	Visibility toward NE, 6 miles
Light ground fog		50	49	SW	3		
Light fog	1,015.9	50	49	SE	6	29.99	
Dense fog	1,014.9	46	46	S-SE	4	29.94	
Light smoke	1,015.2	52	48	SE	10	29.97	
Light fog	1,014.7	50	48	SE	8	29.95	
	1,016.3	50	46	SE	5	30.00	Variable scattered to broken
Light fog	1,015.9	51	46	S	7	29.99	
		50	47	SW	7		
	1,016.6	58	46	SSE	10	30.01	Breaks in overcast
	1,015.6	58	46	SE	8	29.98	Radio range unreliable
Haze	1,015.9	50	45	W	4	29.98	Radio range unreliable
	1,015.6	58	45	E-SE	6	29.98	
	1,015.6	58	43	S-SW	9	29.98	
	1,015.9	58	42	S	19 strong gusts	29.99	
	1,014.9	58	40	S	16	29.95	

Winds Aloft

What They Are. Neither the wind direction nor its velocity has the same values at different elevations above the surface. In hourly sequence reports, the wind direction and velocity refer to conditions at or near the surface of the earth. By the term "winds aloft" is meant the wind values at various elevations above the earth. Wind velocities aloft are usually greater than the surface velocity. Hills, forests, and buildings tend to diminish surface velocities. At an elevation of 2,000 feet, the wind velocity is likely to be twice the surface value. In our part of the world, at elevations of 3 or 4 miles or more, the wind blows almost constantly from directions between southwest and northwest.

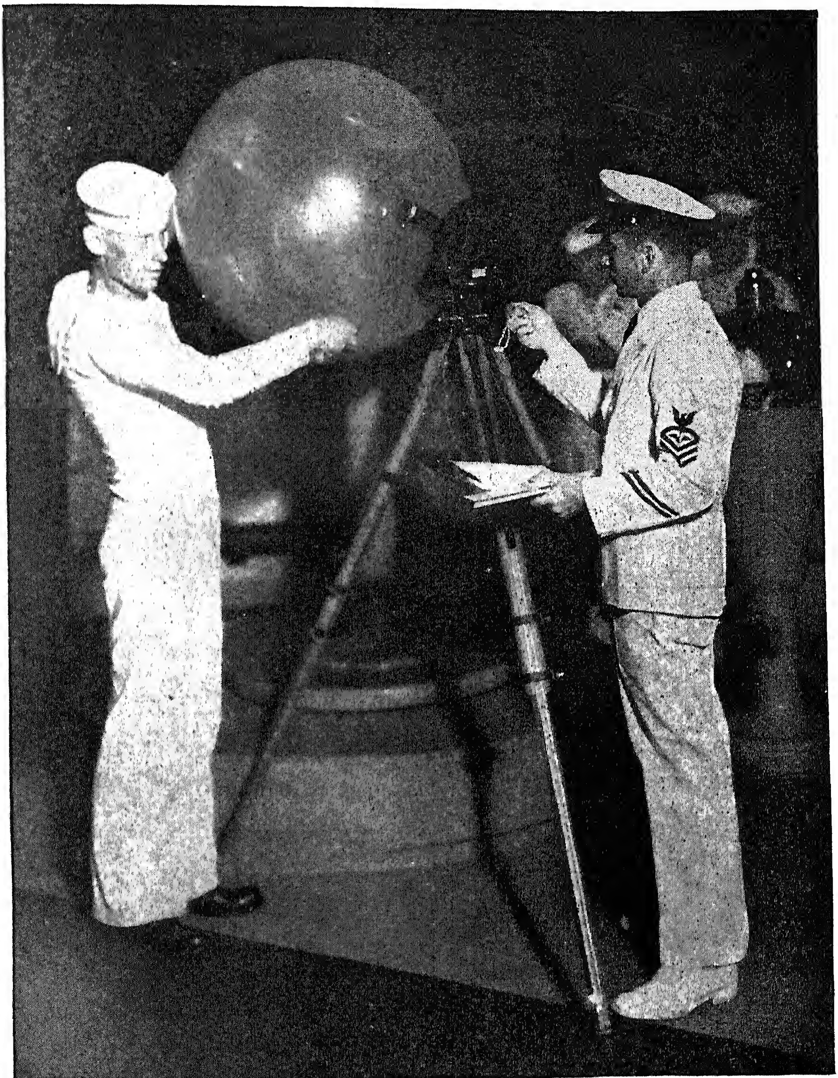
Winds Aloft Sequence

SR18 01011 0603 22408 2414 42520 2627 62729 2730 82632
HBJ17 01910 2414 22015 1908 41804 2207 62612 2715 82616 2618 02616 2616
22616 2612 42610
AZ17 01813 1819 22014 2210 42409 2808 63410 3512 83516
LG18 01808 1807 20904
HT18 PIRA
OJ18 PICO
BW17 01412 1818 21821 1824
PEH18 01706 1808 21804 0502 40108 3518
PW18 PIFI
HMW19 PIFI
IB17 01715 1720 21819 1915 41914 2116 62218 2318

How Winds Aloft Are Determined. More than one hundred Army, Navy, and Weather Bureau airport stations are equipped to determine the winds aloft (Fig. 124). The observations are made every 6 hours. Rubber balloons about 30 inches in diameter are inflated with enough hydrogen or helium so that they have a known ascension rate when released. Their path is watched through a telescope which is a part of a theodolite. This instrument resembles a surveyor's transit and is used to measure the vertical and horizontal angles that the balloon makes as it is carried with the winds at various elevations (Fig. 36). At night a small lantern is attached, and the light is observed during night observations.

How Winds Aloft Reports Are Used. The data tabulated during the pilot balloon observation are readily converted into

values of wind velocity and direction at 1,000-foot intervals above sea level. By means of teletype communication, winds

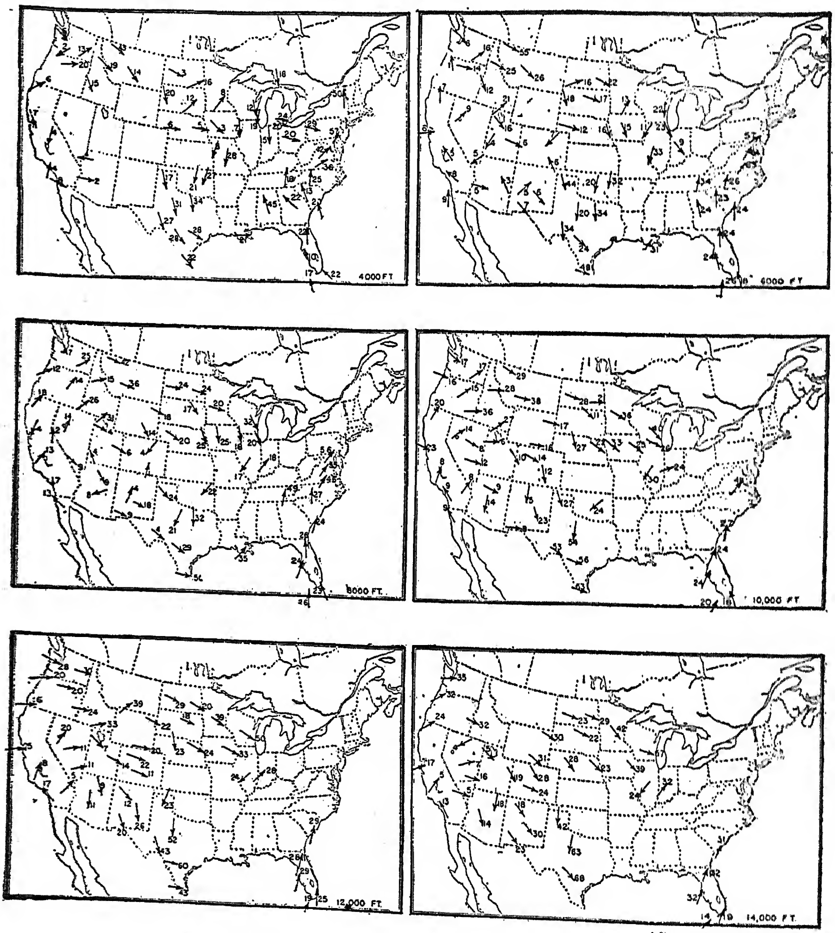


(Official photograph, U.S. Navy.)

FIG. 124.—Night balloon readings aboard U.S.S. *Wright*.

aloft reports are exchanged so that stations have reports from all parts of the country. Most airport weather stations prepare winds aloft charts. Figure 125 shows a chart prepared from

observations made at 5 P.M. on April 18, 1940. Such charts are considered when preparing weather forecasts. Pilots use them in selecting flight altitudes. An attempt is made to select flight elevations where tail winds prevail or where head winds have low velocities.



(*Courtesy of C.A.A.*)

FIG. 125.—Winds-aloft chart for 1700 E.S.T., April 18, 1940.

How Winds Aloft Are Reported. Winds aloft observations are coded before they are sent to other stations by teletype. This is necessary in order to save time and avoid confusion. The table on page 216 shows a typical winds aloft sequence. The first report in this sequence is translated as follows:

As coded	Translation		
SR 18	Syracuse, N.Y., 6 P.M. (24-hour clock)		
	Feet above Sea Level	*Wind Direction, 360-degree Scale*	*Wind Velocity, Miles per Hour*
0 10 11	0 (at surface)	100°	11
06 03	1,000	60°	3
2 24 08	2,000	240°	8
24 14	3,000	240°	14
4 25 20	4,000	250°	20
26 27	5,000	260°	27
6 27 29	6,000	270°	29
27 30	7,000	270°	30
8 26 32	8,000	260°	32

It will be noted that when coding the wind direction, the zero in the unit place is omitted. Also, the figure is omitted which designates the elevation for the odd thousands of feet of elevation.

The other station designators in this table are as follows:

HBJ	Burlington, Vt. (City Office)
AZ	Albany, N.Y. (Municipal Airport)
LG	La Guardia Field, New York, N.Y.
HT	Hartford, Conn. (Brainard Field)
OJ	Springfield, Mass. (Westover Field)
BW	Boston, Mass. (Municipal Airport)
PEH	Nantucket, Mass.
PW	Portland, Me. (Municipal Airport)
HMW	Mount Washington, N.H.
IB	Caribou, Me. (Municipal Airport)

PIRA, which stands for pilot balloon and rain, is sent when no observation is made because of rain. PICO is transmitted when low clouds prevent an observation. PIFI means an observation was not filed for transmission.

Surface Weather Maps for Aviation

When and How They Are Made. At 2:30 and 8:30 A.M. and P.M. Eastern War Time all stations make very complete reports of weather conditions which are important for map making and

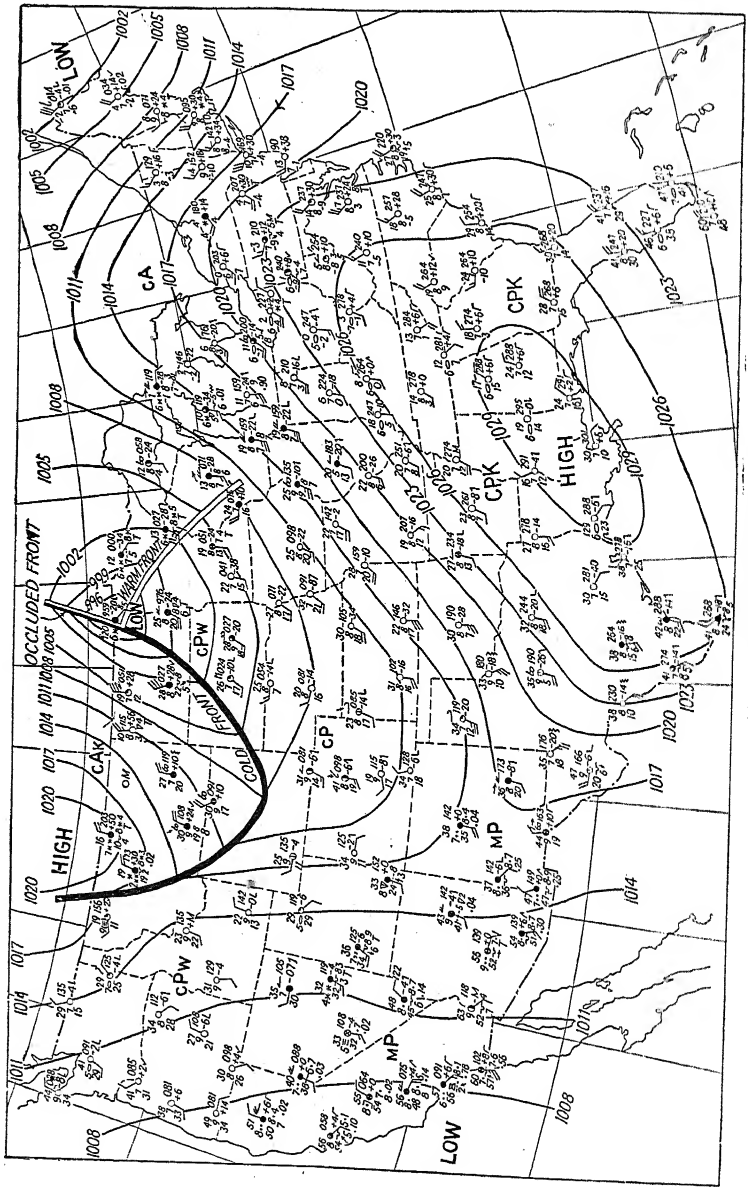


FIG. 126.—Surface map.

forecasting. The reports do not resemble hourly reports but are sent in numeral code. Stations exchange these reports by means of teletype and other methods of communication. At most airport stations a weather map is prepared every 6 hours. This is done

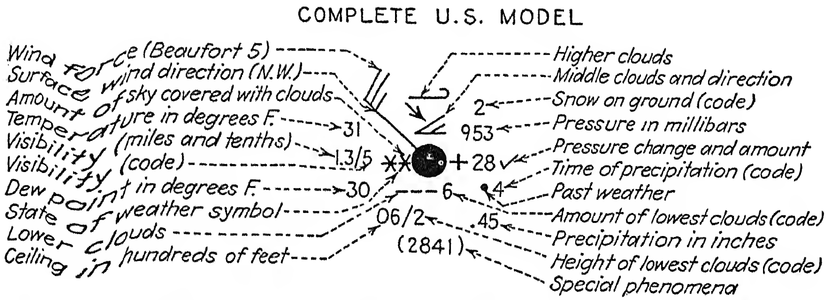
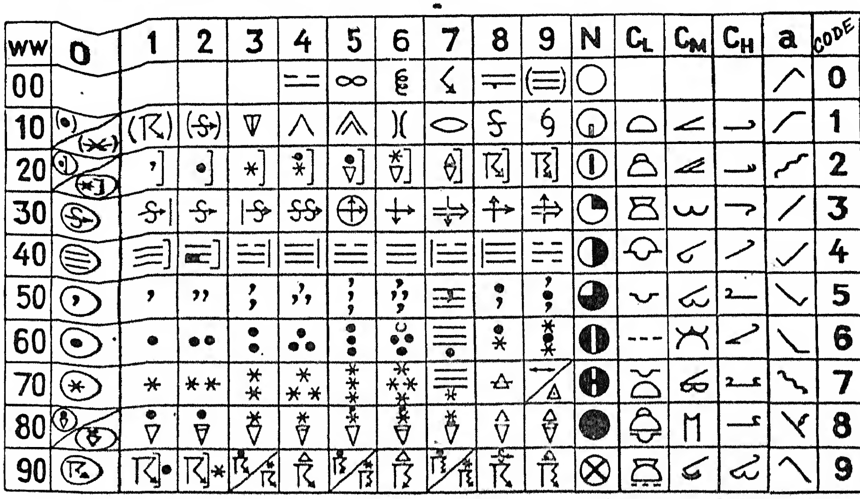


FIG 127.—Station model adopted by the U.S. Weather Bureau on August 1, 1942.



(*Courtesy of U.S. Weather Bureau.*)

FIG. 128.—Table of symbols. Columns *ww* to 9 show map weather symbols. The filled-in portion of the circles in column *N* represent the approximate portion of the sky which is covered with clouds. Columns C_L, C_M, and C_H contain symbols representing low, medium, and high altitude clouds. The symbols in column *a* represent the trend of the barograph trace during the three hours prior to a report.

by decoding the reports and entering on base maps the values of the elements reported (Fig. 126). The report from each station is entered around the circle that represents that particular station (Fig. 127). The state of weather symbols, and the cloud and

pressure change symbols are shown in Fig. 128. The meaning of some of the map weather symbols are as follows (see Fig. 128):

∞ Haze
= Fog
Signs of tropical storm
Dust or sand storm
,', Continuous moderate drizzle
: Intermittent moderate rain
*** Continuous heavy snow in flakes
Showers of heavy rain
Thunderstorm

Some of the cloud symbols shown in Fig. 128 represent cloud types as follows:

Cumulus of fine weather
Layer of stratus or stratocumulus
--- Low broken-up clouds of bad weather
Cumulonimbus
Typical altostratus, thin
Veil of cirrostratus covering the whole sky.

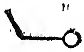
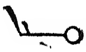
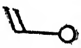
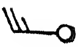
The arrows fly with the wind. Thus, the wind indicated in Fig. 127 is blowing from the northwest. The wind velocity is shown by barbs on the tail of the arrow. A short barb represents a Beaufort force of 1; a long barb represents a Beaufort force of 2, as shown in the table on page 223.

Black lines, called *isobars*, are drawn to connect stations that report the same barometric readings. These lines encircle large areas of high and low pressure. Air masses are labeled in blue in the cases of those originating in the north, whereas those from tropical regions are shown in red. Frontal surfaces appear as lines on the surface map. Cold fronts are shown in blue, warm fronts in red, and occluded fronts are colored purple. Areas where precipitation is occurring are shaded green.

The Use of the Weather Map. The weather map presents to the pilot a picture of weather conditions over a large area. It helps him to understand the official forecast. After looking at the

map he will have a much better understanding of the weather conditions he will encounter during flight and will know better

BEAUFORT TABLE OF WIND VELOCITIES

Beaufort Number	*Map Symbol*	*Descriptive Word*[1]	*Velocity, Miles per Hour*	*Specifications for Estimating Velocities*
0		Calm.......	Less than 1	Smoke rises vertically.
1			1–3........	Direction of wind shown by smoke drift but not by wind vanes.
2		Light.......	4–7........	Wind felt on face; leaves rustle; ordinary vane moved by wind.
3		Gentle......	8–12.......	Leaves and small twigs in constant motion, wind extends light flag.
4		Moderate...	13–18......	Raises dust and loose paper; small branches are moved.
5		Fresh.......	19–24......	Small trees in leaf begin sway; crested wavelets form on inland water.
6			25–31......	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty.
7		Strong......	32–38......	Whole trees in motion; inconvenience felt in walking against the wind.
8		....	39–46......	Breaks twigs off trees; generally impedes progress.
9		Gale........	47–54......	Slight structural damage occurs (chimney pots and slate removed).
10			55–63......	Trees uprooted; considerable structural damage occurs.
11		Whole gale..	64–75......	Rarely experienced; accompanied by widespread damage.
12		Hurricane...	Above 75...	

[1] Except "calm," these terms not to be used in reports of velocity.

what to do if poor conditions develop. The forecaster bases his forecasts on the surface map together with charts of upper-air conditions, preceding charts, and other data.

Winds Aloft Charts

How They Are Prepared. At most airports winds aloft charts are prepared every 6 hours. On these charts the wind direction is shown by an arrow flying with the wind, and directions are indicated to 16 points of the compass. The velocity is indicated in miles per hour instead of by means of the Beaufort scale, as is the case on the surface map. The directions and velocities of winds aloft are plotted for even thousands of feet above sea level for each station.

Uses of Winds Aloft Charts. The pilot may see at a glance the air currents at various flight levels. Winds aloft charts also show him possibilities of shifts in wind directions and velocity. These charts are useful in the preparation of forecasts.

Airway Forecasts

At district forecast centers a large staff of forecasters and map men are on duty 24 hours a day. They prepare a variety of maps, supplementary charts, and diagrams useful in forecasting. At these centers, forecasts are prepared every 6 hours for the various airways and for important terminals, or airports, in the district. The forecasts are in general distributed to other stations by teletype and are broadcast to pilots in flight. The forecasts are for a period 8 hours in advance. A typical forecast, abbreviated as transmitted by teletype, is as follows:

CGCX CGWG OHRK OHDV MPHR MPYX MPDH MPDM. CLR OR SCTD CLDS IN WRM DRY AIR OVR DIST XCP ST OVC AT 1 TO 2 THSD AND LCLY AT LESS THAN 5 HND TIL 0800C WRN NEB XTRM NERN COLO AND XTRM SERN WYO. VSBY LWRG GNRLY TO 1 TO 2 MIS IN SMOKE TO LEE LARGER CITIES ABT SUNRS AND IPVG TO OVR 6 BY 0930C. VSBY OVR 6 ELSW XCP LESS THAN 1 IN GNDFG XTRM WRN NEB NRN COLO AND XTRM SERN WYO TIL 0800C.

CG TRML. CLR OR SCTD VSBY NEAR 3 LWRG TO 1 TO 2 IN SMOKE BY 0600C THEN IPVG TO 2 TO 4 BY 0900C AND TO NEAR 6 BY 1100C.

MK TRML. CLR OR SCTD VSBY 11/2 TO 3 WITH SMOKE LMTG, IPVG TO 3 to 6 BY 0900C AND TO 6 OR BTR BY 1030C.

MA WU AN HR YL YX GF TRMLS. CLR OR SCTD VSBY OVR 6.

The meaning of this forecast message is as follows:

Airways: Chicago—Cheyenne, Chicago—Winnipeg, Omaha—Bismark, Omaha—Denver, Minneapolis—Huron, Minneapolis—Sioux City, Minneapolis—Duluth, Minneapolis—Des Moines. Clear or scattered clouds in warm dry air over district except stratus overcast at 1 to 2 thousand and locally at less than 5 hundred until 8 A.M. Central Time western Nebraska extreme northern Colorado and extreme southeastern Wyoming. Visibility lowering generally to 1 to 2 miles in smoke to lee larger cities about sunrise and improving to over 6 by 9:30 A.M. Central Time. Visibility over 6 elsewhere except less than 1 in groundfog extreme Western Nebraska Northern Colorado and extreme southeastern Wyoming until 8:00 A.M. Central Time. Chicago Terminal. Clear or scattered visibility near 3 lowering to 1 to 2 in smoke by 6:00 Central Time then improving to 2 to 4 by 9:00 A.M. Central Time and to near 6 by 11:00 A.M. Central Time.
Milwaukee Terminal. Clear or scattered visibility 1½ to 3 with smoke limiting, improving to 3 to 6 by 9:00 A.M. Central Time and to 6 or better by 10:30 A.M. Central Time.
Madison, Watertown, Aberdeen, Huron, Sioux Falls, Sioux City and Grand Forks Terminals. Clear or scattered visibility over six.

Services of Weather Bureau Personnel

Before beginning a flight the airport Weather Bureau office should be visited. There the pilot receives help concerning data about existing weather conditions and can obtain forecasts for the area in which his flight will be made. If weather conditions are favorable, winds aloft information is needed in planning cross-country flights. The observer or forecaster on duty will gladly aid in furnishing winds aloft data and in interpreting weather conditions.

Communication Services

The Civil Aeronautics Administration of the Department of Commerce has established communication stations at most airports located along the civil airways. These offices are usually located next door to the Weather Bureau offices. Among the duties of communication offices are (1) to send and receive weather reports, forecasts, and other messages by teletype (a sort of electric typewriter); and (2) to broadcast weather information at various scheduled times. A communication sta-

tion is assigned a certain radio frequency for broadcasting purposes. Each station is tuned in constantly on certain frequencies that are used by planes in calling communication stations.

Commercial Air-line Weather Staffs

Organization and Duties in the United States. Most of the observational work needed for flying in the United States is done by the U.S. Weather Bureau. Duties that are performed by meteorological staffs of commercial air lines operating in the United States are as follows: (1) To give meteorological instruction to pilots, flight dispatchers, and other personnel. This may be accomplished by a series of lectures, correspondence courses, and meetings. Much material can be covered in even a short series of lectures, because the pilots have much firsthand experience with many of the topics that are treated. Both the pilots and meteorologists are benefited when meetings are arranged to discuss weather problems. (2) To confer with flight dispatchers, pilots, and others concerning forecasts and weather situations in connection with specific flights. (3) If time is available, an air-line meteorologist may perform other duties such as flight dispatching and miscellaneous types of office work.

Weather Work in Airlines Extending Beyond the United States. As in the United States, some other nations have well-developed meteorological organizations. However, in some countries the weather services are not adequate for the operation of air lines. In those cases an air-line meteorological department is faced with the necessity of organizing and training observers to staff observing and reporting weather stations. This entails the installation and maintenance of adequate instrumental equipment.

At commercial air-line stops the companies maintain radio equipment with which communication can be maintained with the planes. Weather information, among other things, is reported by and to the pilots.

Observation of Weather by Pilots

Wind. The surface wind direction should be checked, before taking off or landing, by noting the wind vane or wind cone. In flight, away from the airport, the surface wind direction is deter-

mined by observing the drift of smoke and dust or by noting the wind's effect on water, vegetation, and other objects. An alert pilot keeps in mind the possible necessity of a forced landing and during flights keeps aware of surface wind directions so that a landing may be made into the wind if possible. The wind direction and velocity at flight levels is determined from time to time by navigation methods.

The Pilot in Flight Watches Other Phenomena. Because of the distance between reporting stations, weather reports do not always include every condition or change that would be encountered by pilots flying cross country. Forecasts, even at best, cannot be expected to anticipate every weather change that may occur. The pilot then will want to be alert to notice approaching thunderstorms and phenomena that affect the visibility and ceiling, such as fog, clouds, and snow. Ground fog and ordinary fog are formed under certain conditions of temperature, wind, and cloud situation of the sky. By watching these conditions a pilot can anticipate and note more promptly the formation of fog.

Weather Reports by Pilots in Flight. Pilots are encouraged to report, by radio, phenomena that are observed at flight levels. Typical data of this sort are bases and tops of cloud layers, formation of ice on the plane, and air temperatures at various elevations. The station that receives these data transmits them to other stations by means of the teletype, and it is broadcast to other pilots.

Summary

In time of peace the countries of the world cooperate by radio in exchanging weather information. In our country the U.S. Weather Bureau regularly broadcasts meteorological data to pilots. This is accomplished through the communication facilities of the Civil Aeronautics Administration, which maintains offices next door to most weather stations. Also, pilots may visit weather offices to examine reports and charts, and trained bureau forecasters and observers are on duty day and night to render assistance in planning flights. During time of war pilots and others receive needed information, but the Weather Bureau avoids revealing data that would be likely to fall into enemy

hands. Descriptions in the chapter refer to services available to anyone in time of peace. All pilots should learn to read weather maps and weather reports.

Information needed by pilots includes: the surface wind direction and velocity where taking off or landing, and gusty conditions if existing; the ceiling; the existence of fog, and its effect on the visibility; the possibility of ice formation on the plane and in the carburetor; the wind conditions at flight levels; the likelihood of smooth or rough air in flight; and the outlook as to thunderstorm activity, which should be avoided in most cases. Decoding of the elements of a weather report is explained. Many of the instruments used in recording weather are described; others are shown in Appendix C. Chapter IX will explain a number of ways in which a knowledge of weather conditions is applied to flight conditions; further, various effects of weather in aviation are shown.

Questions

1. What weather elements determine the classification of the weather at a station?

2. Is the visibility determined by eye observation or by an instrument?

3. How is the ceiling measured during daylight hours? At night?

4. What is a clinometer?

5. If a ceiling balloon has an ascension rate of approximately 400 feet per minute, what is the ceiling if the balloon is observed to enter the base of an overcast cloud layer 3 minutes 20 seconds after being released.

6. Referring to Fig. 118 what would be the height of the base of the cloud if the angle, as measured, is 70° and the base line is 1,000 feet?

7. With further reference to Fig. 118 what would be the height of the base of the cloud if the angle, as measured, is 60°, the base line being 500 feet?

8. Are ceilings reported as the heights of cloud-layer bases above sea level or above the ground?

9. What weather elements are of particular interest to pilots?

10. Name two phenomena that can considerably reduce the visibility for a pilot attempting a landing.

11. In a weather report what units are used to express the atmospheric pressure?

12. In an hourly sequence report, to how many points of the compass is the wind direction reported?

13. In making a pilot-balloon observation at night, how can the path of the balloon be observed?

14. How often are regular surface weather observations made at a Weather Bureau airport station?

Study Fig. 127, and answer questions 15 to 25.

15. Is the wind blowing from the southeast or the northwest?

16. What is the ceiling?

17. Has the barometer been rising or falling during the 3-hour period prior to the observation?

18. What is the dew point?

19. Is the sky condition overcast, broken, scattered, or clear?

20. What is the wind force in terms of the Beaufort scale? Convert that force into terms of miles per hour.

21. What is the visibility?

22. Refer to Fig. 128 and find the symbols of clouds present in Fig. 127.

23. What "weather" symbols are recorded?

24. Is the barometric pressure expressed in inches or millibars, and what is its value?

25. From what direction are the middle type clouds moving?

26. What is the difference between state, airway, and terminal forecasts?

27. Which parts of a sequence weather report may be determined from equipment inside the office?

28. How may a weather report be received by a pilot in flight?

29. Explain how gusty wind is coded in a sequence report.

30. Discuss special observations.

31. Of what value is a radiosonde observation?

32. In pilot balloon reports, is the wind velocity recorded in terms of the Beaufort scale or in miles per hour?

33. From how many different directions are winds aloft reported?

34. What weather phenomena should a pilot watch while in flight?

35. What duties do the personnel of a commercial air-line weather staff perform?

36. Why should a pilot be alert to weather conditions?

37. In what way may a pilot make use of consultation service at an airport weather bureau office?

38. What time of day is represented by 1830E?

39. What is the meaning of X in the classification of weather?

40. Beside X, name two other classifications of the weather.

41. Give a few station designators.

42. Describe the four symbols that indicate the sky condition in a sequence report.

43. In what decade did rapid advancement begin in the development of meteorology for pilots?

44. Name a few conditions under which special observations are made and reported.

45. Are pilot-balloon observations practicable in cloudy weather?

46. Does cloudy weather interfere with radiosonde observations?

47. Describe the duties of a CAA communication station.

Suggested Activities

1. Visit a Weather Bureau airport station and make a list of all the instruments. Indicate where they are installed, *i.e.*, whether they are on the roof, in the office, or near the ground.

2. Ask a pilot what weather information he has found useful in cross-country flying and in local flying.

3. Observe and record three times each day for 2 weeks the following weather elements: precipitation, atmospheric pressure, temperature, wind direction, sky condition, kind of clouds, and visibility. Note the values of these elements on days before and days after precipitation periods.

4. Secure a series of published weather maps for the 2-week period for which you observed the weather (activity 3). Compare your observations with those shown on the maps. Note the positions of the lows, highs, air masses, and fronts.

5. Make a list of books and periodicals that are concerned with aeronautical meteorology.

6. Write a description of weather conditions before, during, and after a rainy spell.

7. Visit a Weather Bureau airport station, and note the various types of work being done there. Which activity do you think you would most enjoy doing each day?

Topics for Class Reports

1. Poor types of flying weather.
2. Weather service for transoceanic flights.
3. Air-line flying without the aid of weather service.
4. Weather information useful for local flying.
5. Principles involved in weather instrument construction.
6. Pilot-balloon observations.

7. The CAA communication service.
8. Local weather signs and forecasting.

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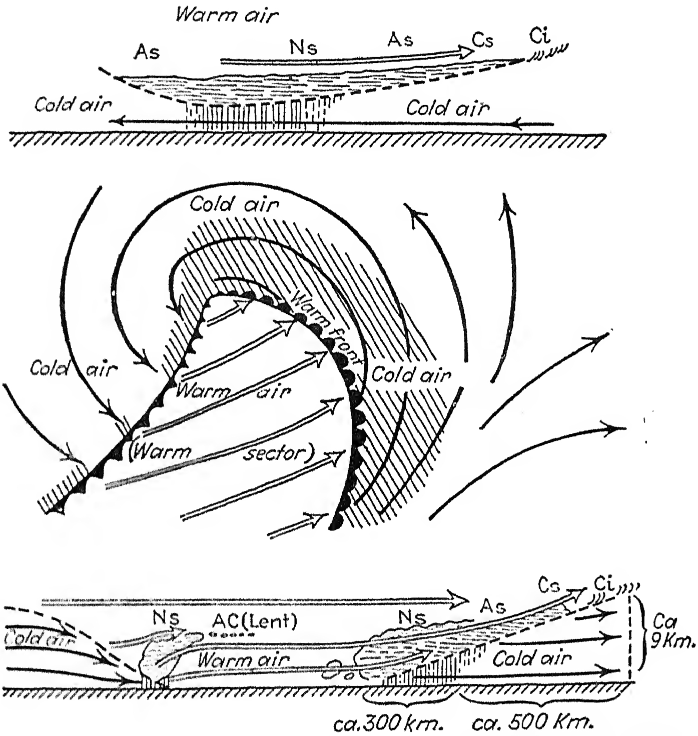
Chapter IX. Weather Applications to Aviation

Aviation and Weather Knowledge Have Developed Together. Not so many years ago there was very little thought about, or need for, information concerning such matters as ceiling, visibility, turbulence, gustiness, icing, and ground fog. Today such elements are important both in peace and in war, because they have so much significance in aviation. The need for reporting and forecasting these conditions has stimulated the development of meteorology. Also, airplane flights have been the source of much information about weather processes. On the other hand, the science of meteorology has contributed largely to the present-day safety and efficiency of aviation.

Pressure Areas. It has been realized for many years that weather conditions and changes are associated with high- and low-pressure systems in the atmosphere which move across the country from west to east. These areas are usually several hundred miles in diameter, and their centers travel at an average rate of 500 miles or more a day. Cloudiness, storms, precipitation, and warmer temperatures are related to the lows, whereas the highs commonly bring fair and cooler conditions. The lows and highs are plotted from reports of weather conditions existing near the earth's surface.

The Upper Structure of Pressure Systems. During the past century studies and writings have been made by a number of meteorologists concerning weather processes at upper levels of the atmosphere. Various writers have contributed to the knowledge of upper-air processes that cause clouds and rain. During the First World War J. Bjerknes, a Norwegian meteorologist, conducted research work that lead to important results. He examined a number of lows by carefully noting detailed weather

reports from a dense network of weather stations. In a paper consisting of only eight pages he described a theory concerning both the horizontal and vertical structure of lows. This theory, announced in 1918, has done much to stimulate further thought. It has aided weather forecasting, especially the detailed, short-period type that is helpful to pilots. It has also furthered under-



(From Weems, *Air Navigation.*)

FIG. 129.—The cyclone (depression) model.

standing of the many weather phenomena that are encountered in flight.

Air-mass and Frontal Analysis

J. Bjerknes and H. Solberg Low Model. Figure 129 illustrates the horizontal and the vertical sections of a low-pressure system according to Bjerknes. The central one of the three views shows a mass of warm moist air flowing from the southwest toward the northeast. Cold air is shown to the east, north, and

west of the central warm-air sector. The notched line separates, at the earth's surface, the warm and cold air masses. The right-hand portion of the line is known as the *warm front*. As the low moves eastward, or to the right, the warm front is the region where warm air begins to occupy land formerly occupied by cold air. The left portion of the notched line is the *cold front* where cold air is occupying land formerly held by warm air. The lower view shows a vertical cross section through the southern part of the low. On the right side of this view the warm southwesterly stream is shown flowing up over the dense cold air. To the left is shown the cold dense northwesterly stream underrunning, wedge fashion, the warm mass. The upper view represents a vertical section through the northern part of the low. Here the cold easterly stream is seen flowing beneath the warm southwesterly mass.

Air Masses and Fronts. It will be recalled from Chap. V that an air mass is a considerable volume of air that has existed for some time over a definite area and has developed temperature and humidity properties characteristic of the area. Also, a front is a surface that exists between two air masses of different density. In Fig. 129 it will be noted that a front is truly a surface, but it appears as a line in both the horizontal and vertical views. Air masses and their reaction with the earth and along fronts have a very definite relation to aviation activities.

Flight in Certain Air-mass and Frontal Conditions

The Warm Front. Refer to the lower view in Fig. 129 and imagine that you are located at the eastern edge of the low, flying west at an elevation of 2,000 feet. The wind at the flight level is from the south. High above, at an elevation of 20,000 feet or more, will be noted cirrus, cirrostratus, and possibly cirrocumulus clouds. In fact, to an observer located east of the low, one of the first indications of the approach of the storm area is the appearance of those cloud types, especially if the cirrostratus clouds extend across the sky in the form of long bands. Those clouds are formed mainly because the warm-sector air is expanding and cooling as it slides up the warm front. Continuing westward, altostratus, altocumulus, stratus, and nimbostratus clouds, which exist at lower levels, will be noted. Rain or drizzle

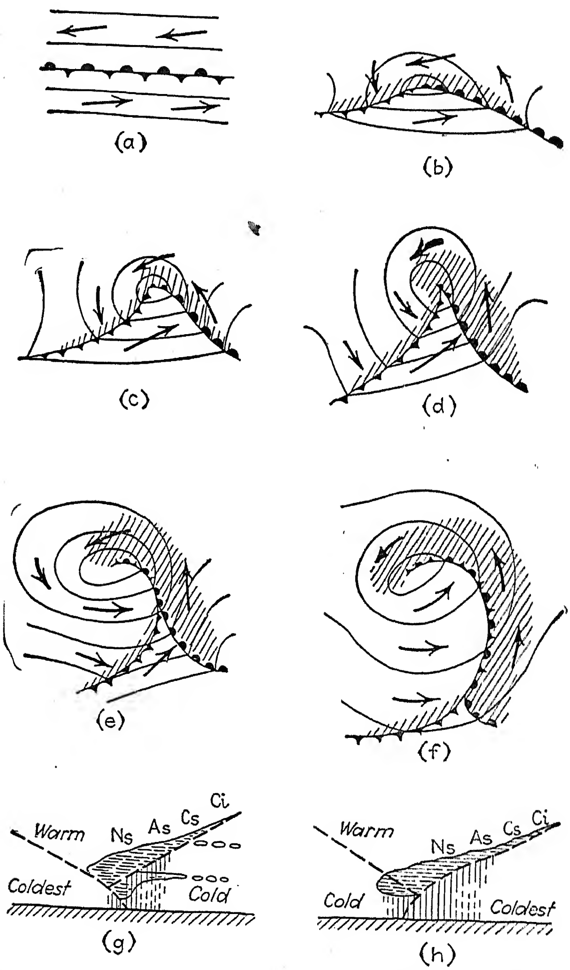
is likely to be encountered in connection with the three stratus types. As the precipitation falls through the cold air mass, fog and possibly low stratus clouds are likely to form. With certain temperature conditions freezing rain, or sleet, may be encountered beneath the warm front. A definitely widespread area of low clouds, fog, and precipitation is typical of warm-front situations. These conditions often result in low ceilings, poor visibility, and icing, for which the pilot must be alert.

Warm-sector Maritime Tropical Air. If the trip is continued westward into the region of the warm sector, the wind there is found to be from the southwest, and the air temperature is warmer. If the air is warmer than the land over which it is moving, it is possible that fog and stratus clouds will be encountered. On the other hand, if the air is cooler than the land, cumulus clouds will probably exist. The barometric pressure will continue to drop or remain low until the cold front is reached.

The Cold Front. Refer to the lower view in Fig. 129. At the cold front the cold wedge of air forces the warm air upward forming cumulus, stratocumulus, or cumulonimbus clouds. Precipitation in the form of showers, possibly heavy in amount but of comparatively short duration, is typical of conditions near the surface position of the cold front. Turbulence and gustiness are present normally to elevations of 6,000 feet or more. Thunderstorms are often strung along cold fronts, in which cases stormy conditions exist up to 20,000 feet or more. When a cold front passes a locality the pressure begins to rise and the temperature falls. There occurs a decided shift in the wind direction from a southerly to a westerly direction. Other typical changes associated with a cold-front passage are the ending of precipitation, a decrease in cloudiness, and a lowering of the dew-point reading. An entirely different air mass exists behind, or to the west, of the cold front.

Continental Polar Air. Let us assume that the air mass west of the cold front had remained for some time over that part of North America which is north of the region of the prevailing westerlies. In that case it would be low in water-vapor content. If its temperature near the earth's surface is colder than the ground over which it moves, flights will be rough, especially at lower levels. This would be due to thermal currents established

because of the warming of the air at the earth's surface. Surface visibilities would be good except where the wind might be picking up and carrying dust.



(*From Weems, Air Navigation.*)

FIG. 130.—Showing the development of a depression. (Full line-isobars.)

Occlusions. Cold fronts ordinarily move toward the east about twice as fast as warm fronts. When the cold front overtakes the warm front the warm sector is squeezed aloft, and an occlusion results. If the air to the west is colder than that to the east, the occlusion is a cold front type (Fig. 130*g*). If the reverse

is true, the occlusion would be a warm front type (Fig. 130*h*). Stratus clouds and rain or drizzle are typical of warm-front occlusions, whereas cumulo form clouds and showers are associated with cold-front occlusions.

The Beginning and Development of a Low. Meteorologists of Norway have pointed out one process that involves the formation and development of a low. This is shown in Fig. 130*a* to *f*. In *a* we see a stationary front with cold air to the north and warm air to the south. A wave in the front, accompanied by a drop in pressure and a counterclockwise wind circulation, is shown in *b*. Stages of development similar to that of Fig. 129 are shown in *c* and *d*. Conditions of occlusion are represented in *e* and *f*.

Wind and Air Currents as Related to Flying

The term *wind* is applied to air that is in horizontal motion. Currents, as distinguished from wind, refer to the motion of air in a vertical direction. Other terms used with reference to air circulation are as follows:

Turbulence relates to disturbances in the atmosphere caused by temperature differences or by air friction with the earth's surface.

Eddies are local vortexes found in turbulent air.

Gusts refer to sudden increases of short duration in the wind velocity. They are caused by eddies in turbulent air.

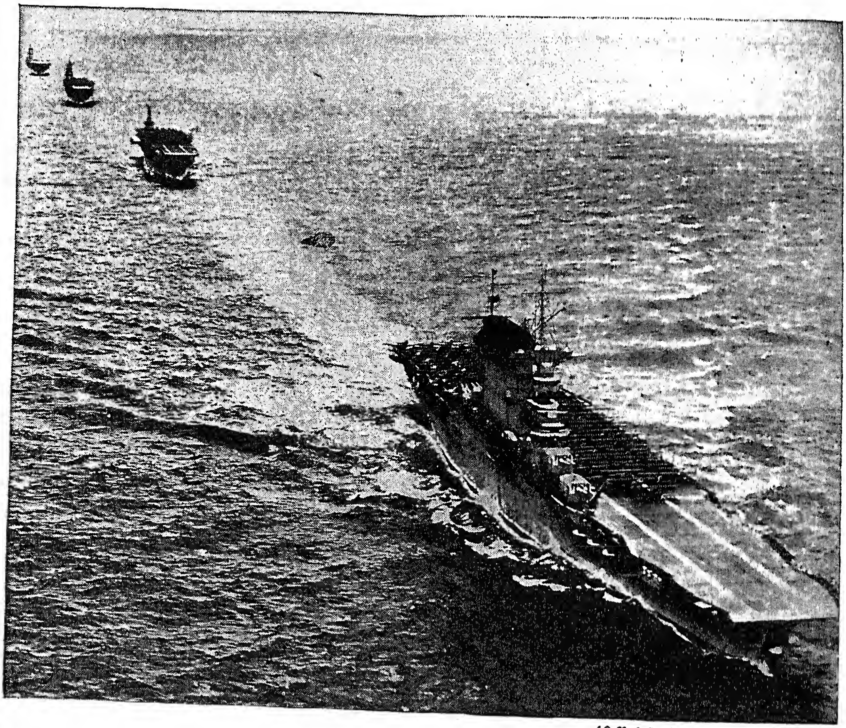
Squalls are similar to gusts but are of longer duration.

Surface Wind.—The lift necessary to maintain an airplane in flight depends on the air speed, or the motion of the airplane relative to the air through which it is moving. Planes take off into the wind, *i.e.*, toward the direction from which the wind is blowing. In this way the necessary air speed is achieved sooner than if the airplane were pointed in the other direction. The required ground speed, or speed of the airplane over the ground, is less, and the necessary length of run is shorter when made into the wind. Care must be used when taking off into a gusty wind. A sudden lull, or decrease in wind velocity, will require a longer run.

Airplanes land into the wind for the same reason. The ground speed is less when landing, the length of run needed after landing is less, and the airplane may be brought to a stop sooner. While

landing, a gust or lull may cause the airplane to undershoot or overshoot; *i.e.*, to land short of or beyond the intended point. Strong winds require much care while taxiing, lest the airplane tip and be damaged.

In the Navy an airplane is always catapulted into the wind, and aircraft carriers head into the wind when planes are leaving or returning to the flight deck. Figure 131 shows the U.S.S.



(*Official photograph, U.S. Navy.*

FIG. 131.—U.S.S. *Lexington*, U.S.S. *Ranger*, U.S.S. *Yorktown* and U.S.S. *Enterprise*.

Lexington, U.S.S. *Ranger*, U.S.S. *Yorktown*, and the U.S.S. *Enterprise*, aircraft carriers, steaming in formation at sea.

Thin Air. Air is thinner, *i.e.*, it has less density, when the pressure is low or when its temperature increases. An airplane climbs slower in thin air, and the required take-off run is longer. Longer runways are needed at airports high above sea level (*e.g.*, Denver), than at lower elevations.

The Wind at Flight Levels. In calm air the ground speed is the same as the air speed. When a wind is blowing, the ground

speed of an airplane flying with the wind is equal to the wind velocity plus the air speed. When the plane is flying into the wind, the ground speed is equal to the air speed minus the wind velocity. In the case of an automobile the gas consumption is specified in terms of the number of miles it will travel on 1 gallon of gas. The fuel consumption of an airplane is described as the number of gallons used per hour of cruising time. The number of miles an airplane will cover in 1 hour is affected by the wind and is equivalent to the ground speed rather than the air speed. For example, let us consider a small 65-horsepower airplane, carrying a capacity of 12 gallons of gas, which consumes 3 gallons of gas per hour at the usual cruising speed. It is customary in problems of navigation to consider one-fourth of the gasoline supply as a reserve. In calm air the airplane can cruise for 3 hours and cover 240 miles, if the cruising speed is 80 miles per hour. With a head wind of 20 miles per hour it can cover 180 miles, or with a tail wind it can cover 300 miles. Since these are typical figures, the importance of wind can easily be seen.

An important principle that all pilots should understand is this: it always requires more time to fly across country to a distant point and return when there is wind, regardless of its direction, than when there is no wind. It is assumed that the wind remains the same in direction and velocity during the trip. The following extreme case clearly illustrates this. An airplane whose air speed is 60 miles per hour flies with a tail wind of 60 miles per hour. It would of course cover 120 miles in 1 hour. At the end of an hour it turns and heads toward the point of departure. Its ground speed then would be zero, and it would not be able to return under those conditions. The principle also can be verified with less extreme conditions of wind velocity. In the study of navigation a student learns how to compute the maximum distance, under given wind conditions, that an airplane can fly and still be able to return using a specified amount of fuel. When the wind is blowing from a direction at right angles to an airplane's heading, its effect on the time for a round trip is at a minimum, for a given wind velocity.

The wind velocity is usually less near the surface than at higher elevations. Therefore, airplanes fly at higher elevations when tail winds prevail but fly closer to the surface in the cases

of head winds. Furthermore, in our country the wind direction at very high elevations is west. To take advantage of these winds planes flying east fly high. For trips west, a lower elevation is selected where velocities may not be so great or where the wind may blow from other directions.

At an elevation of 1,500 to 2,000 feet the velocity is likely to be about twice the surface velocity. At that elevation the wind direction is often about 35 degrees clockwise from the surface direction.

Thermal Turbulence, What It Is. When the sun shines on a lake shore, air currents rise over the sandy beach and descend over the water area. This is due to the beach's becoming much warmer than the adjacent water surface. The air overlying the sand becomes warm and expands. It is pushed upward by cooler air, which moves in horizontally from adjacent areas. An airplane over the lake will experience a decided bump or rise as it reaches the air above the shore line. When flying in the opposite direction it will take a sharp drop when it arrives over the lake. These bumps, or drops, were formerly known as "air pockets" because of the apparent variations in the lifting qualities of the air. Actually they are due to vertical ascending and descending air currents.

Similarly air rises and descends over regions that are composed of alternate areas of plowed fields, pastures, forests, and roadways. Cumulus clouds mark the tops of rising air currents. The bases of such clouds mark the elevation at which the rising air has cooled, because of expansion, to the dew-point temperature at that elevation. The tops of the clouds indicate the uppermost limit at which the air's vertical motion exists.

How to Avoid Thermal Turbulence in Flight. Flights made during the early morning or late afternoon hours are effective in avoiding thermal turbulence. Night flights too are smoother in this respect. During the late morning and early afternoon hours bumps may be avoided by flying above or around cumulus cloud formations. It should be noted that cumulus cloud heights are greater during the hotter part of the day.

Because of a lack of thermal currents, flights over water areas are smoother than over land. Flights tend to be smooth on days when the sky is overcast with a layer of stratus type clouds. That

is because the cloud layer blocks the heating effect of the sun, which would be necessary to create thermal currents. On sunny days following a rainy spell, when the ground is quite wet, thermal currents are not so active, because much of the sun's heat is used to evaporate the ground's moisture rather than to heat the ground itself. Flights over snow-covered areas are likely to be quite smooth.

Commercial air lines are alert to avoid flight at levels where marked turbulence exists. Passenger comfort is more important than the saving of any time that might result in flying at turbulent levels where favoring winds may exist.

Mechanical Turbulence, What It Is. This type of turbulence is the result of eddies that are created when air flows over the rough surface of the earth or over built-up areas. It is also found along frontal surfaces.

How to Avoid Mechanical Turbulence. In order to avoid turbulence over rough terrain, it is necessary to fly at a sufficiently high elevation so as to clear the eddies present. Flight at 2,000 feet ordinarily should be high enough. Eddies are specially associated with the lee sides of mountains, hills, and bluffs. Such eddies may be carried horizontally for a considerable distance at times when the wind is strong. At airports wind disturbances also are found on the lee side of hangars and other buildings, and the eddies may be carried by the wind to landing areas. This should be kept in mind when making take-offs and landings.

Turbulence associated with a cold front is usually quite active, and in order to clear it a flight elevation of 6,000 feet or more is needed. When thunderstorm activity is continuous along a cold front, it is advisable to turn back, make a landing and wait for it to pass.

Gusts at Flight Levels. In the case of a head wind a gust causes a bump, and a lull will cause a plane to drop a certain amount. These reactions were formerly known as "air pockets," and in effect are similar to upward and downward currents referred to in the paragraph Thermal Turbulence, What It Is.

Updrafts and Downdrafts. It is important to realize that, when wind blows over a hill, mountain, building, or other object, an updraft on the windward side and a downdraft on the leeward side are created. Consider Fig. 132. It is apparent that as the

airplane approaches the mountain, the upward current helps it to clear the peak. On the downwind side the plane is carried downward by the current, but the airplane is flying in a direction away from the side of the mountain and is not likely to be endangered.

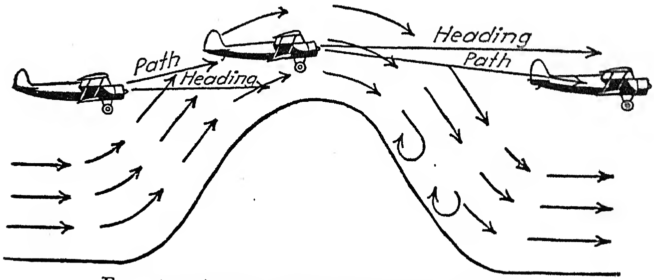


FIG. 132.—Flying with updraft and downdraft.

Now consider Fig. 133. It is evident that as the airplane approaches the mountain it is carried downward by the downdraft at a time when it should be gaining altitude in order to clear the summit. Also, the eddies, which prevail on the leeward side, aggravate the situation and make it difficult to stay out of trouble. No amount of flying in the downdraft back and forth parallel to the mountain would result in gaining the required

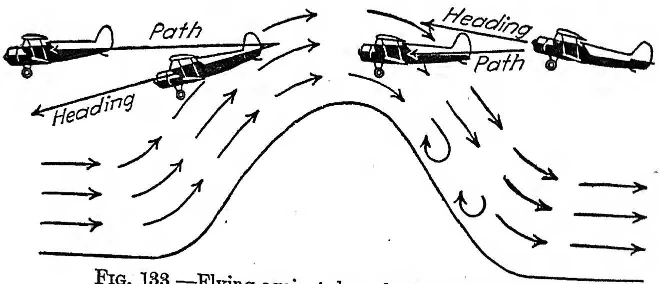


FIG. 133.—Flying against downdraft and updraft.

elevation. The solution is to fly away from the mountain and gain the necessary elevation. This situation has caused much trouble in the past. An airplane that succeeds in clearing the top will find itself in an updraft on the windward side. This will afford no danger, for the plane will be flying away from the mountainside.

It should be mentioned that thermal currents are often encountered over mountain peaks, and they help an airplane to gain elevation.

Difficulties associated with the windward side are due to fog, cloudiness, precipitation, and thunderstorm activity, which result because of the rising, expansion, and cooling of the air currents there.

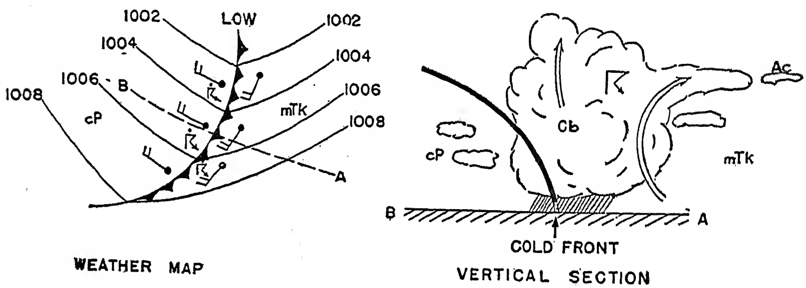
Soaring. The ability of a glider to remain aloft depends on the existence of ascending air currents. Such currents are found on the windward sides of hills and mountains, where the air is forced to rise as it crosses higher ground. Rising air currents exist beneath cumulus clouds. During sunny days rising currents may be found over plowed fields, roads, buildings, mountain summits, and sandy or other barren areas, whereas downward currents take place over lakes, streams, forests, meadows, and other areas that are heated less rapidly than their surroundings. After a glider is launched from a hill, with a truck or airplane tow, or by other means, its ability to remain aloft is dependent on skillful gliding within ascending air currents.

Valley Breezes. During the day the sides of mountains become heated, and upward convectional currents are induced. In daytime an airplane flying in a valley will encounter a breeze blowing up the valley. At night the mountains become chill because of radiation, and cold air from the mountainside drains down the valleys much like water flowing.

Relation of Thunderstorms to Flying

Why Thunderstorms Are Dangerous. Thunderstorms are hazards to aviation because they are associated with turbulence, gustiness, lightning, and often hail. Their most serious feature with respect to flying is the vertical currents, which no doubt often exceed 100 miles per hour. An airplane that becomes involved in an upward or downward current is likely to get out of control and may become damaged or wrecked because of the strong forces to which it is subjected. Strong gusts, or decided changes in the wind velocity, may have the same effect. Lightning damages radio sets and aerials but in general does not seem to cause serious damage to an airplane. Of course attempt should be made to avoid it and thereby avoid the other dangerous

features of thunderstorms. Serious damage to the propeller and other parts of an airplane results from hail. The more intense the thunderstorm the larger the hailstones are likely to be. Cold-front thunderstorms (Fig. 134) are the strongest and most serious type. They can occur during either day or night. A continuous string of thunderstorms often extends along a cold front for hundreds of miles. The windward sides of mountains are regions favorable for the formation of both day and night thunderstorms. These are particularly treacherous because (1) a plane may not have sufficient altitude and can easily be dashed into the mountain, and (2) individual peaks may be hidden by the cloud masses.



(*Courtesy of C.A.A.*)

FIG. 134.—Cold-front type thunderstorm.

How to Avoid Thunderstorm Difficulties. Some thunderstorms are mild; others are severe. Many rules have been formulated concerning flying in or near thunderstorms. The safest rule is to avoid them. In general they move from west to east at an average speed of 30 miles per hour. Their direction of travel is related to the direction of the wind at near 10,000 feet elevation. Because they are ordinarily local phenomena of comparatively small diameter, it is usually easy to fly around them. Their great height makes it impractical to fly over them. A thunderstorm that is confronted while an airplane is flying toward the north should be passed by turning to the left. This procedure will result in the airplane's remaining clear of it as the storm travels eastward. If confronted with a series of cold-front thunderstorms a pilot may find it necessary to make a landing and wait for the front to pass. In that case the airplane should be hangared or securely tied down.

Ice Formation on the Airplane

Its Cause and Effect. Ice tends to form on an airplane when it flys through condensed water vapor such as drizzle, rain, clouds, or fog, the temperature of the air being 35°F. or below. Serious icing is most likely within a temperature range of 27° to 35°F. The expansional cooling of the air as it flows around the wing often results in the droplets' freezing and sticking when air temperatures are between 32° and 35°F. A situation of unfrozen water droplets, the temperatures of which are less than freezing, is a common phenomena in air temperatures below 32°. As an airplane moves through such an area of droplets they stick and instantly freeze to the various surfaces of the airplane. The most serious result of airplane icing when it forms on the wings is the loss of lifting efficiency. Figure 135 shows how ice forms near the leading edges of a wing. It often destroys the smooth flow of air

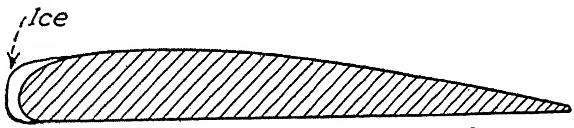


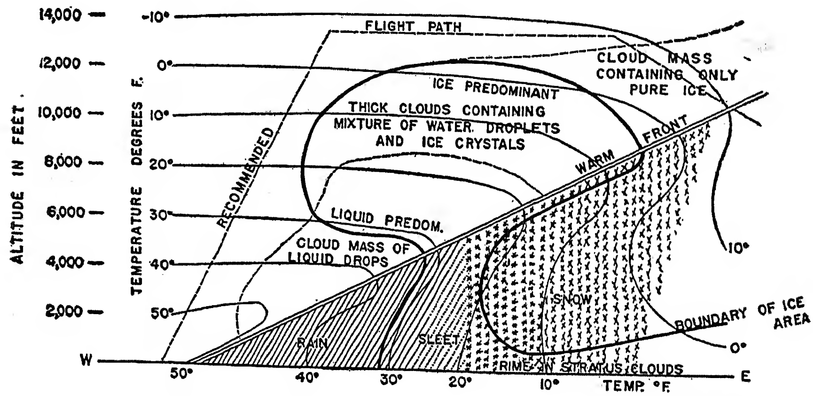
Fig. 135.—Formation of ice on an airfoil.

past the wing, which is essential in creating the necessary lift. Other effects of icing are (1) it makes difficult the control of the plane, (2) it reduces the propeller efficiency, (3) it increases the drag, (4) it increases the load of the airplane, and (5) it may cause vibration of the propeller and other parts.

What to Do about Icing. The leading edges of wings may be fitted with pneumatic boots that can be alternately inflated and deflated, thereby tending to crack off the ice as it forms. Propellers can be protected by means of an antifreeze solution which they receive by centrifugal action from the hub. The pilot should prevent icing by avoiding areas in which it can form. If ice starts to form the pilot should do one of five things: (1) land, (2) turn back, (3) climb several hundred feet higher if a warmer current of air is known to exist there, (4) descend several hundred feet where temperatures are normally higher, or (5) climb quickly to higher levels if the clouds are thin and shallow.

Figure 136 shows a recommended flight path in order to avoid icing conditions at a warm front.

Frost may form on an airplane that is staked out over night. If so, it should be removed from the wings prior to take-off. This is necessary because it would tend to destroy the smooth flow of air past the wings and would reduce lift. A longer run would be needed before the plane would take off.



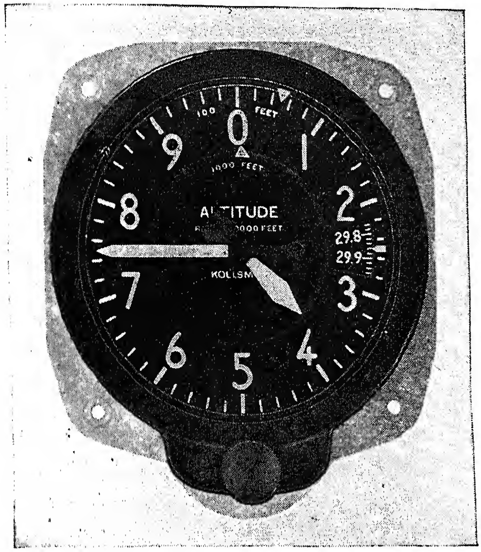
(*Courtesy of C.A.A.*)

FIG. 136.—A warm-front icing situation.

Effect of Weather on the Altimeter

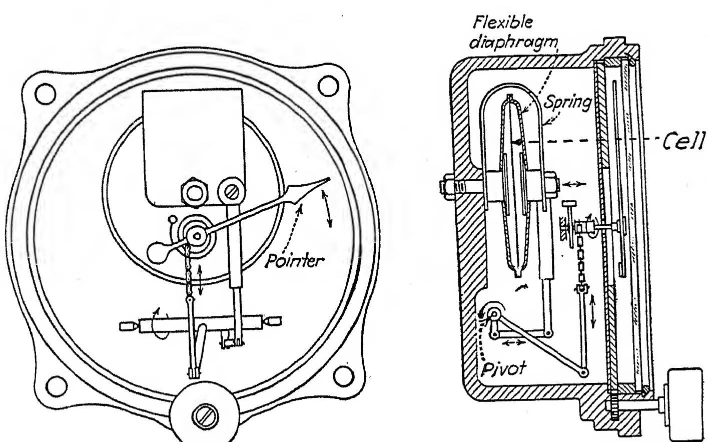
The Principle of the Altimeter. The higher the elevation, the lower the atmospheric pressure. When a barometer (Fig. 156) is carried upward into the atmosphere it will indicate a lower pressure reading. Within several thousand feet of the earth an increase of 1,000 feet in elevation is associated with a decrease of 1 inch of mercury in the reading of a barometer. An altimeter is a modification of the aneroid type of barometer. When an altimeter is carried upward 1,000 feet its dial arrangement indicates 1,000 feet additional elevation above the earth, instead of a decrease of 1 inch of mercury, as in the case of the dial of an aneroid barometer. The altimeter can therefore be used to determine the position of an airplane in a vertical direction. Figure 137 shows the dial of an altimeter, whereas Fig. 138 shows how its mechanism operates. In Fig. 137 the dial reads 3,750 feet. The inside of the cell, Fig. 138, is exhausted of air. It is prevented from collapsing by the spring. At high altitudes the pressure on the outside of

the cell is less than at lower elevations. Differences in the pressure on the cell result in movement of the spring to the right or left.



(*Courtesy of Kollsman Instrument Division of Square D Company.*)

FIG. 137.—Sensitive altimeter.



(*From Shields, Airpilot Training.*)

FIG. 138.—Simple altimeter.

This movement is transmitted by means of levers and chains to the pointer on the dial.

Effect of Pressure Variations. At any location the pressure is constantly changing. If the pressure is becoming lower, the altimeter will read higher. The altimeter should be set to read zero before take-off. During flight it will then indicate the elevation above the point of take-off, except for certain errors, one of which is due to general pressure changes in the locality.

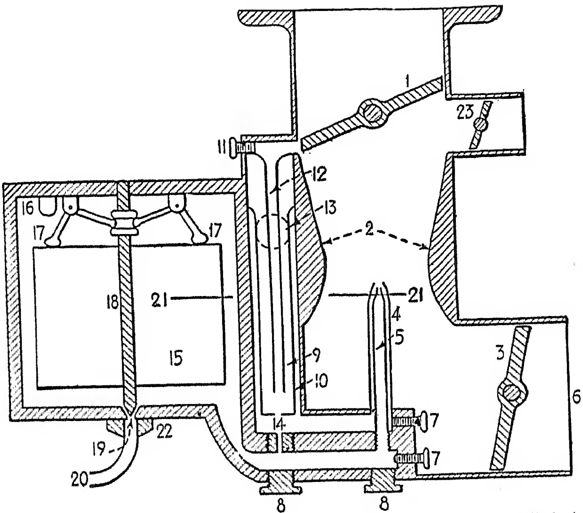
Effect of Temperature. The altimeter is arranged to read correctly in so-called *standard* conditions of temperature. If the air temperature is warmer than standard, the air then is less dense, or lighter per unit volume. Under those conditions let us set the altimeter to read zero at the surface, and then take it up to an elevation of 1,000 feet. It will then actually read less than 1,000 feet, because the movement up through the light air will not affect the altimeter as in the case of air of standard temperature and density. An altimeter will overread when operating in air the temperature of which is below that of standard air.

The Altimeter Setting. Altimeters of the so-called *sensitive* type can be adjusted in flight. The altimeter setting is an expression, in inches of mercury, of the station pressure reduced to the sea-level value. The pilot merely receives by radio the local altimeter setting prior to landing and adjusts his altimeter. It will then read correctly during the landing. Altimeters of this type indicate elevations above sea level rather than above the point of take-off.

Weather and Carburetor Icing

Description of a Carburetor and Its Function. The carburetor is a device that furnishes a mixture of gasoline and air to the airplane's engine. In order to provide the proper type of mixture, the carburetor vaporizes the gasoline by means of an atomizer and causes it to be mixed with the right amount of air. A diagram of the Zenith carburetor is shown in Fig. 139. Motion of the pistons within the cylinders draws in air at 6. In the Venturi throat shown at 2 the air mixes with vaporized gasoline, which is atomized by jet 4. The resultant mixture is drawn into the cylinders through the top of the carburetor. The amount of the mixture, and hence the speed of the motor, is controlled by the butterfly or throttle valve shown at 1.

How Ice Forms in a Carburetor. Vaporization requires heat. When the gasoline is vaporized in the Venturi throat heat is extracted from the air in that part of the carburetor. Because of this and other reasons the temperature of the air in the carburetor may be decreased as much as 50° or 60°. If the air is cooled to a temperature below 32°F., and at the same time below the dew point, ice will form in the carburetor. When the tempera-



(*Courtesy of C.A.A.*)

FIG. 139.—Carburetor.

1. Butterfly valve
2. Venturi tube
3. Choke valve
4. Cap jet
5. Main jet
6. Air intake
7. Screws to clean channels
8. Jet drain cups
9. Secondary well
10. Primary well
11. Idle adjusting screw
12. Idle tube
13. Air hole
14. Compensator
15. Hollow float
16. Float chamber
17. Counter weights
18. Needle valve
19. Needle valve seat
20. Gasoline line
21. Fuel level
22. Strainer
23. Altitude control valve

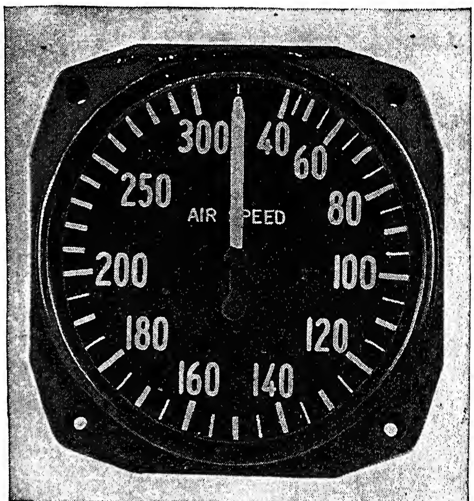
ture of the air through which the plane is flying is 75°F. or lower, the pilot must be aware of the possibility of ice formation in the carburetor. This is particularly true when the relative humidity is high or when flying through precipitation or cloudy areas. For this reason the weather may affect seriously the operation of many types of carburetors.

Effect of Carburetor Ice; Its Prevention. If ice forms on the tip of the atomizer jet, the supply of gasoline is thereby cut off. When ice forms in the Venturi tube, the supply of mixed gasoline vapor and air for the cylinders is decreased or may be entirely

choked off. One method used to prevent carburetor ice is to heat the air before admitting it to the carburetor. This can be done by employing a carburetor air heater that utilizes heat from the engine exhaust gases.

Effect of Weather on the Air-speed Indicator

The Principle of the Air-speed Indicator. The air-speed indicator is an instrument that shows the speed of an airplane through the air. Like the altimeter, its readings are affected by



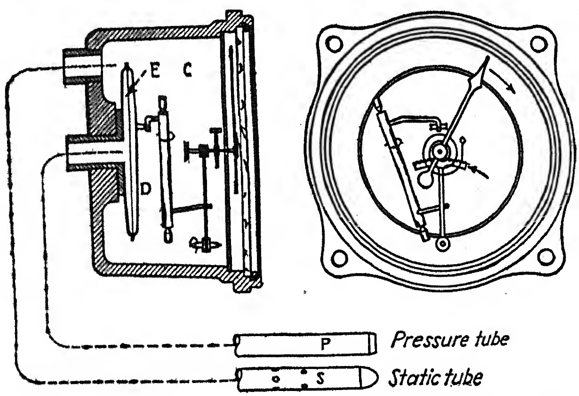
(*Courtesy of Pioneer Instrument Division of Bendix Aviation Corporation.*)

FIG. 140.—Air-speed indicator.

both the air temperature and pressure at flight levels. In Fig. 140 is shown the dial of an air-speed indicator, and a cross section of its mechanism is shown in Fig. 141. The Pitot tube, named for its inventor, is in reality the open end of a copper tube that connects with cell *E* (Fig. 141). The Pitot tube is mounted on a wing or strut so that it points forward like a pistol barrel. The static tube is similarly mounted and connects by copper tubing with chamber *C*. The end of the static tube is closed, but it has air openings along its side. When the airplane is at rest, *C* and *E* are subject to the same air pressure, which is the existing atmospheric pressure. When the airplane is in motion the pressure in *E* is greater because of the impact of the air at the open end of the

Pitot tube. The faster the airplane goes, the greater will be the difference in pressure between C and E. Differences in pressure cause the diaphragm of the cell to bulge varying amounts, and the amount of the bulge is multiplied and translated by a system of levers to a pointer. The pointer indicates on a dial in miles per hour the speed that corresponds to the pressure difference between C and E.

Variations in Atmospheric Pressure Affect the Air-speed Indicator. The air-speed indicator is designed, or calibrated, to read correctly when the density of the air corresponds to normal sea-level conditions of pressure and temperature. Normal pres-



(*From Irvin, Aircraft Instruments.*)

FIG. 141.—Air-speed indicator.

sure at sea level is 29.92 inches. Consider the cases of two airplanes flying at indicated speeds of 80 miles per hour. Let one of the airplanes be flying near sea level, while the other is flying at an elevation of 5,000 feet. The air speed of the airplane at 5,000 feet is actually greater than the speed indicated by the instrument. This is true because the air density at 5,000 is much less that at sea level, and an airplane at an elevation of 5,000 feet must be traveling at a greater speed through the air in order that the instrument will read the same as it would if traveling at that speed near sea level.

Effect of Temperature. Consider now the cases of two airplanes, one flying in air of 59°, the other in air of 89°F. In each case the indicated air speeds and pressure conditions are the same. The warmer air is less dense, and hence the actual air speed

of the airplane flying through it is greater than the actual air speed of the airplane in the colder air.

Thumb Rule for Estimating the True Air Speed. For each 1,000 feet an airplane is above sea level, add 2 per cent of the indicated air speed to the indicated air speed. The result is the approximate air speed of the airplane.

The Stalling Speed Is Correctly Indicated at All Elevations. If an airplane stalls at 40 miles per hour at sea level, the indicated stalling speed at any other elevation will also be 40 miles per hour. This is true because the pressure needed to indicate any given air speed is the same as that upon which flight of the airplane itself depends.

Air-speed Indicator Icing. When flying through rain, mist, or clouds at temperatures near freezing, ice may form in the Pitot tube and render readings unreliable.

Ceiling, Visibility, and Flight

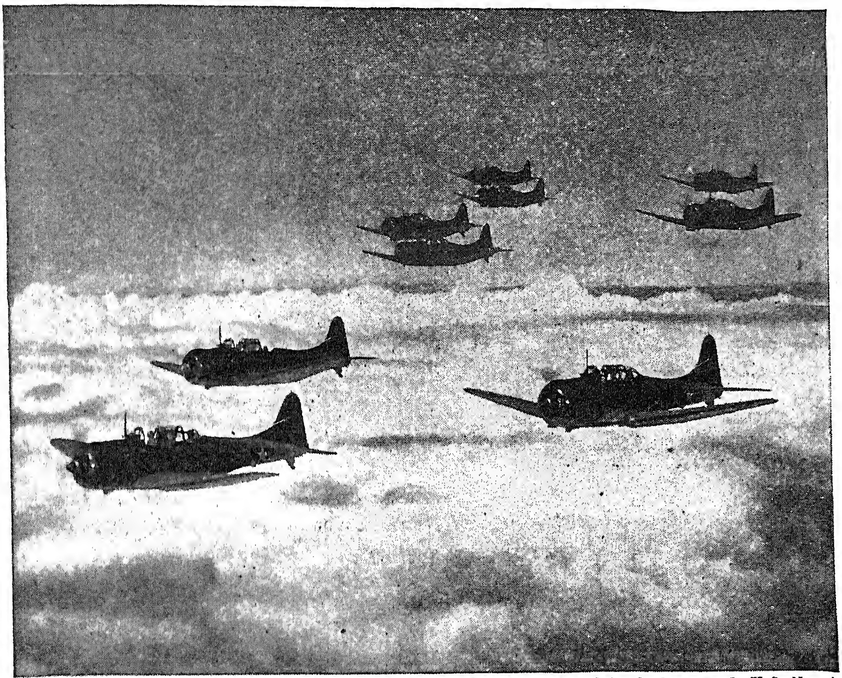
Ceiling

The ceiling, as regards weather conditions, is the distance between the ground and the base of the lowest cloud layer that covers more than one-half of the dome of the sky, as observed from the ground. The ceiling is known as zero if the cloud base is 50 feet or less above the ground. If the cloud base is more than 9,750 feet above the surface of the earth, the ceiling is described as "unlimited." Occasionally in winter it is not possible to determine the ceiling value because of the obstruction to vision which snowfall offers. In that case the ceiling is known as the maximum distance that can be seen vertically through the snow, and the ceiling then is called a "snow ceiling."

Cloud Types and the Ceiling. The three highest cloud types, cirrus, cirrocumulus, and cirrostratus are found for the most part at elevations of 20,000 feet or higher. They do not therefore constitute ceilings. The two intermediate cloud types, altocumulus and altostratus, are found at elevations ranging from 6,500 to 20,000 feet above the surface. Only occasionally are they present at 9,750 feet or below, in which case they can determine ceilings provided they cover more than one-half of the sky dome. Ceilings are principally associated with the five lower type clouds, which are stratus, nimbostratus, stratocumulus, cumulus, and cumulo-

nimbus. These types exist at elevations ranging from near the surface to about 6,500 feet. Figure 142 shows a group of Navy SBD'S of squadron VS-6 in flight over stratocumulus clouds.

Civil Air Regulations for Ceilings and Other Cloud Conditions. At airports when the ceiling is less than 500 feet, aircraft departures and arrivals are not authorized except in the cases of certain public or scheduled air-line flights. This type of weather



(Official photograph, U.S. Navy.)

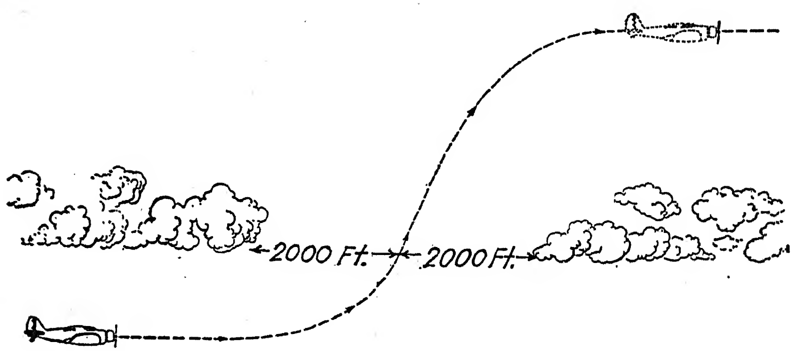
FIG. 142.—Navy bombers flying above stratocumulus clouds.

is known as X, or closed, weather. For a flight when the ceiling is less than 1,000 feet, a plane must be equipped for instrument flight and must observe instrument-flight rules. During such times when the ground cannot be seen, the plane is controlled by reference to instruments. When the ceiling is 1,000 feet or more flight can proceed according to contact-flight rules, *i.e.*, the plane can be flown by reference to the ground.

Flight by Contact Rules. When flying below or above clouds by contact flight rules, a distance from the clouds of at least 500 feet must be maintained. Contact rules permit flying

above the clouds provided the ground can be seen at all times. When ascending or descending between clouds, the clouds must be cleared by at least 2,000 feet (Fig. 143). During contact flight if the ceiling should become less than 1,000 feet, the flight course should be altered, or a landing made.

Nimbostratus and Stratus Ceilings. The two lowest cloud types are stratus and nimbostratus clouds. When present they usually cover more than one-half of the sky and therefore constitute low ceilings. When contact or instrument flights cannot be authorized because of low ceilings, it is usually because of the presence of nimbostratus or stratus clouds.



(*Courtesy of C.A.A.*)

FIG. 143.—Ascent through cloud level.

Cumulus Cloud Ceilings. When cumulus type clouds are expected to increase in amount enough to form a ceiling the ceiling height may be estimated as follows: Divide by $4\frac{1}{2}$ the difference between the surface temperature and the surface dew point. The result multiplied by 1,000 will be the height of the cumulus bases. This is based on the fact that cumulus clouds form because of rising columns of air. In a rising column of air two processes are taking place. First, the dew point decreases about 1°F. for each 1,000 feet of increase in the elevation. This is due to the fact that the rising air is subjected to less pressure at higher elevations. Second, the air cools as it rises and expands. The cooling rate is about 5.5°F. for each rise of 1,000 feet. Therefore, it is evident that the temperature of the air is approaching its dew point at the rate of 4.5°F. per 1,000 feet increase in elevation. The cloud base will form at the elevation where the tem-

perature lowers to the dew-point value at that elevation. The tops of cumulus clouds represent the tops of the rising air columns.

Visibility

In weather reports the visibility is the greatest distance that buildings, hills, and other large objects can be seen horizontally at the ground level. It is assumed that the value applies to an arc representing more than half of the horizon.

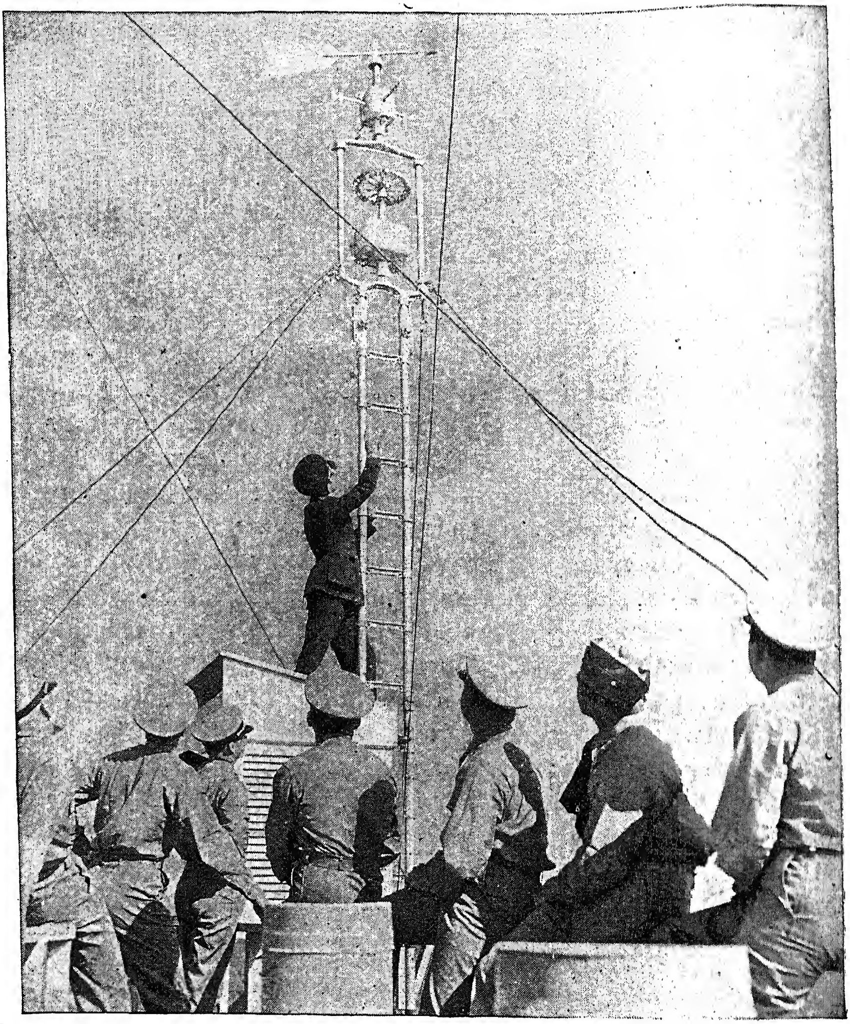
Factors That Restrict Visibility. During flights, especially cross country, when reference to the ground must be made, sufficiently high visibility values are necessary. Rain, snow, drizzle, haze, smoke, and fog are among the phenomena that tend to restrict visibility. Fog and snow, more than anything else, are the most common causes of poor visibility. Pilots watch temperature and dew-point values closely. If the temperature drops to near the dew-point value, fog is imminent. On clear nights when wind velocities are less than about 8 miles an hour ground fog is likely if the temperature drop is sufficient. Low stratus clouds are more likely than fog when wind velocities are more than 8 miles an hour. When the air is calm, ground fog is quite shallow, but it can build up to a considerable depth when circulated by light winds. On cloudy nights, if the skies become clear, a pilot must be alert to a rapid drop in temperature owing to radiation, and the quick formation of ground fog.

Civil Aeronautics Regulations for Visibility. Concerning visibility, X type weather exists when the visibility value is less than 1 mile; aircraft arrivals and departures then cannot be authorized, except in the cases of certain public or scheduled air-line flights. When the visibility is greater than 1 mile, regulations determine whether flights must be made according to instrument flight or contact rules. The regulations are based on whether the flight is made during the day or night, or in the vicinity of, or away from, busy airports.

The Weather in Military and Naval Aviation

In General, the Part of Weather in Warfare. The weather has often been the deciding factor in military campaigns and battles. Napoleon was essentially an artillery officer. His failure

at Waterloo is accounted for in part by his inability, because of the muddy field, to move cannon effectively. In 1588 a possible invasion of England was prevented when a severe storm at sea



(*Official photograph, U.S. Navy.*)

FIG. 144.—Instruction in weather instruments for naval cadets at the Naval Air Station, Pensacola, Florida.

destroyed the powerful Spanish fleet. In 1939 the Axis invaded and successfully conquered Poland during a few weeks of sustained good weather. The fair weather at that time favored

aerial maneuvers and made it possible to move men and equipment quickly. Aviation has become an important and vital part of warfare, and the operation of military and naval aviation is as dependent on weather conditions as is any other type of aviation. Therefore, in order to wage modern warfare successfully, it is essential to have reliable weather information and forecasts.

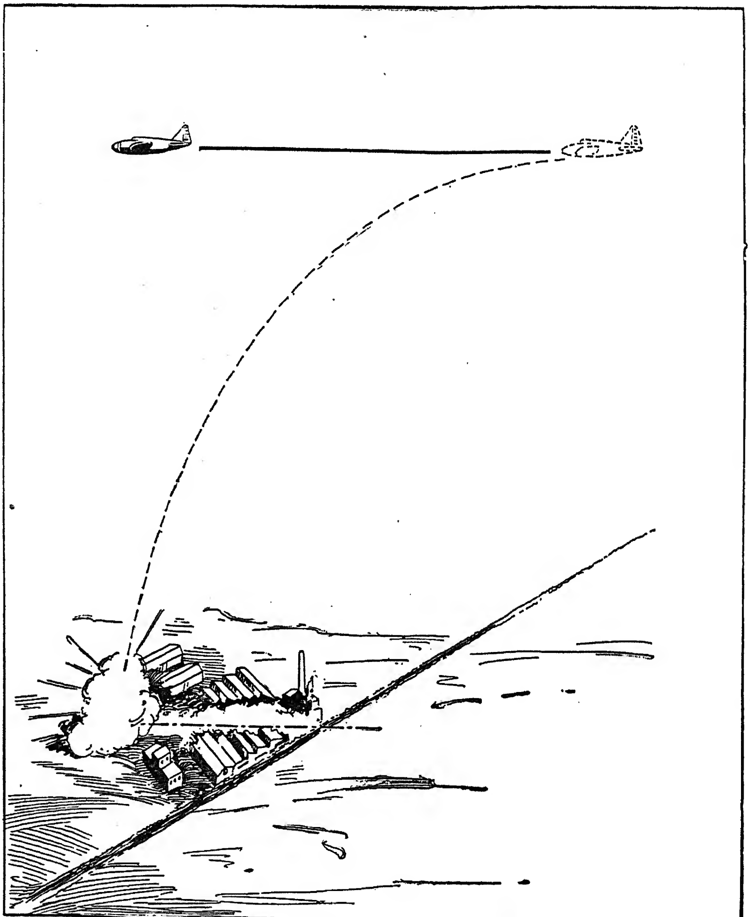
(*Official photograph, U.S. Navy.*)

FIG. 145.—Cadets at the Naval Air Station, Pensacola, Florida, receiving aerological instruction.

Figures 144 and 145 show aviation cadets receiving meteorological (aerological) instruction at the Naval Air Station, Pensacola, Fla.

High-altitude Bombing. When operating at high altitudes, bombers are safer from the antiaircraft fire of land batteries. They are more difficult to see and to hit. High-altitude bombing during the daytime is carried out at elevations above the ground varying from 18,000 to 30,000 feet. At night considerably lower altitudes are flown, particularly if the defenders are likely to be caught unaware. In order to bomb accurately from high levels

the bombardier must be able to see the target. Weather conditions must be such that the ceiling is unlimited and the visibility good. The wind direction at flight level must also be determined. For greater accuracy bombers fly into the wind, *i.e.*, toward the

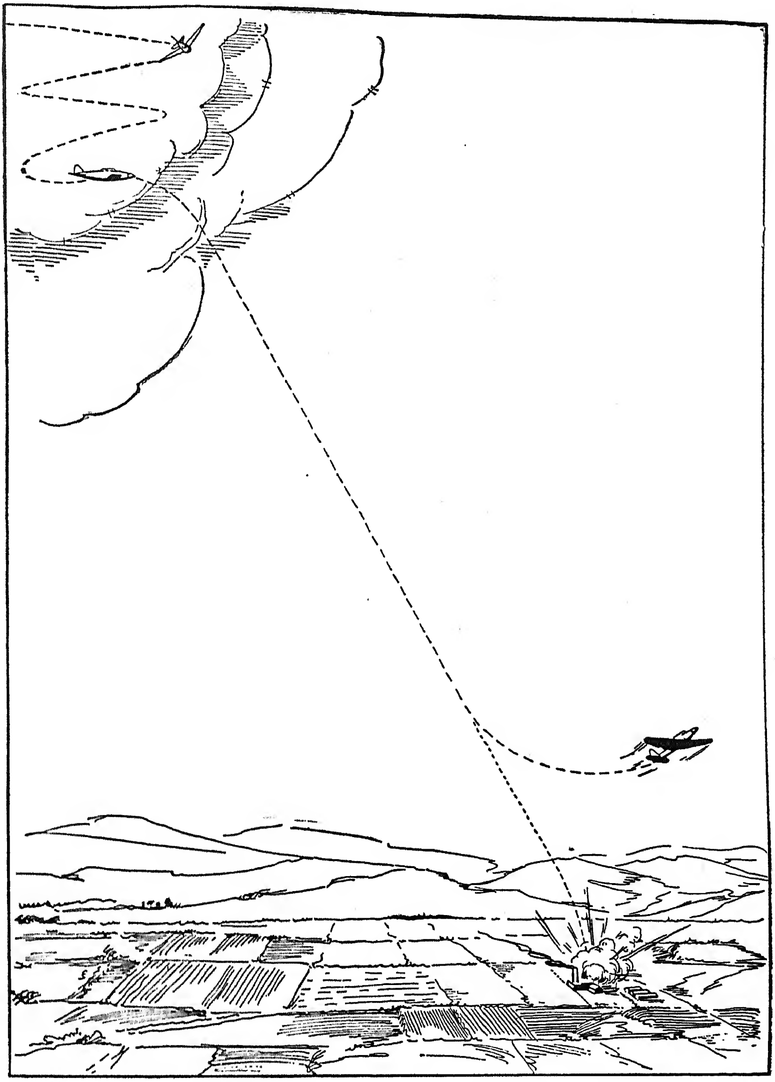


(*Courtesy of U.S. Office of Civilian Defense.*)

FIG. 146.—Precision bombing from a single plane.

direction from which the wind is blowing. The speed of the plane then is slower with reference to the ground, and the bombardier has a longer interval of time in which to aim at the target. Bombers fly downwind (with the wind) when vigorous opposition is expected from the defenders. This results in a shorter length of

time during which the bomber is exposed in the vicinity of the target.

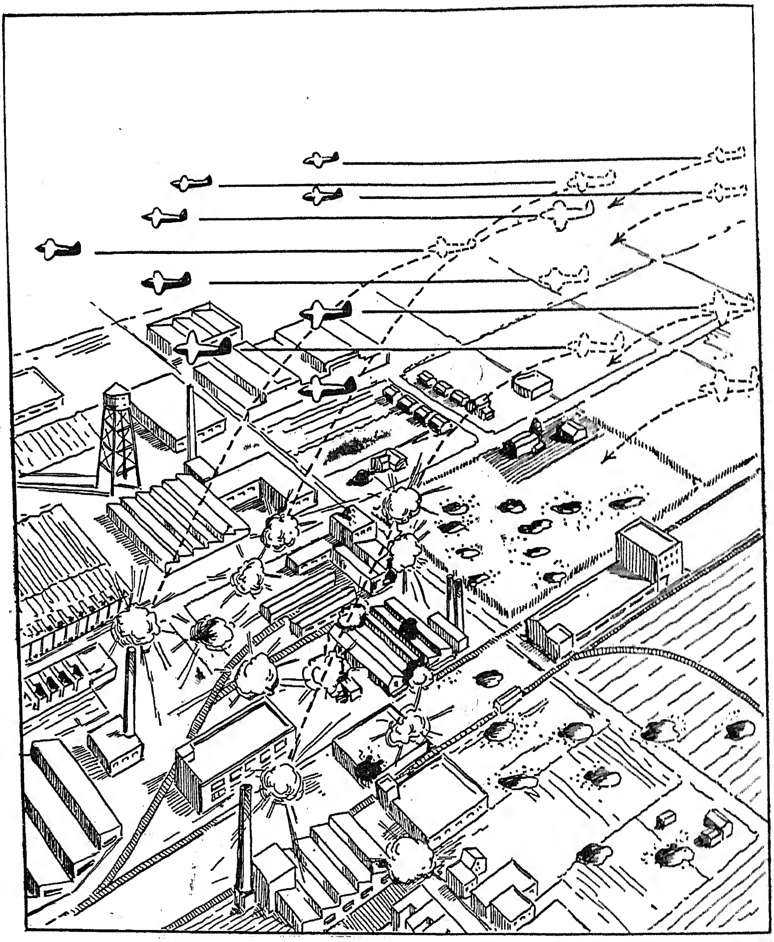


(Courtesy of U.S. Office of Civilian Defense.)

FIG. 147.—Dive bombing, maneuvering downward from a high altitude, the pilot evades antiaircraft fire until he spots the target. At about 5,000 feet he moves into the dive, releasing the bomb and pulling out at a lower elevation.

Low-altitude Bombing. This type of bombing may be employed when the ceiling is low and the visibility poor. It has

certain advantages. A bomber can often keep out of sight during approach, especially in hilly sections. Surprise and a more definite and precise type of attack are possible at lower elevations.



(*Courtesy of U.S. Office of Civilian Defense.*)

FIG. 148.—Area bombing.

Bombing by Planes in Formation. A target is more likely to be hit when bombs are dropped at the same time by a squadron of planes flying in formation. This is known as area bombing. It can be employed when the target cannot be seen, because of low ceiling or poor visibility. Area bombing is also effective against targets that are spread out, such as large industrial areas.

Dive Bombing. Important, but concentrated or small-sized targets, are likely to be attacked by dive bombers. The general vicinity of the target is approached horizontally at high altitude. When over the target, the plane loses altitude by any of a variety of maneuvers. These maneuvers should enable the plane to avoid attack from the ground or in the air. A final dive is made from an altitude of from 4,000 to 6,000 feet. The bomb is released, and the plane is pulled out of the dive at an elevation of from 800 to 1,200 feet, or possibly higher. Bridges, dams, ships, and power plants are typical objects of attack by dive bombing. Obviously visibility and ceiling conditions must be good in order to carry out dive-bombing operations.

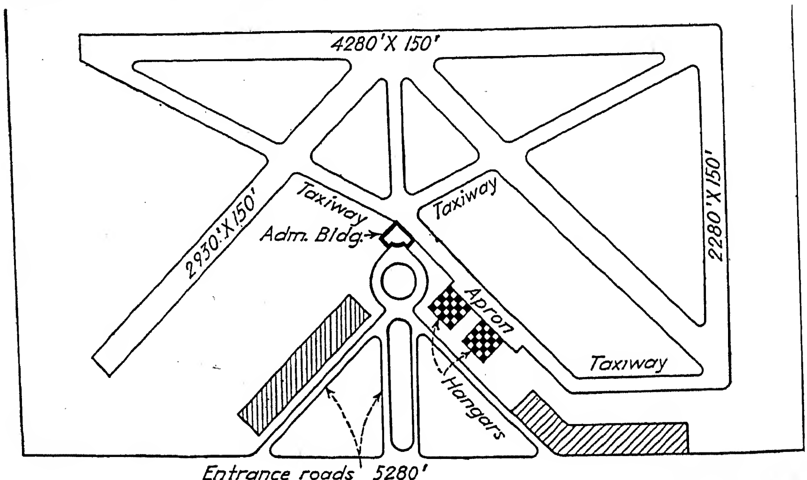
Radio Aid in Bombing. Radio beams may be used to direct bombers to a target, and of course this method may be employed in times of cloudiness and poor visibility. The method involves the installation of radio stations in territory located within a few hundred miles of the target. Bombers directed by radio would not be effective against small concentrated targets, but large areas could be attacked profitably.

Weather in Selecting Airport Sites

Sites in General. Other things being equal, weather statistics should be given serious consideration when selecting the site for an airport. Before studying weather conditions at the several available locations, a number of undesirable places can be eliminated as follows: hills, trees, buildings, high-tension wires, and other obstructions should not be present if they would interfere seriously with airplanes, which must fly low when taking off and landing; the cost of the land and its development should be reasonable; it should be level and capable of being drained; and there should exist adjacent areas capable of being fitted into the original plan, for experience has shown that it is usually necessary to enlarge airports eventually.

Weather Considerations. After eliminating certain sites, as described above, weather records for a year or so should be kept at the remaining available locations. The elements noted should include fog, smoke, low stratus clouds, and the surface wind direction and velocity. Smoke is likely to restrict seriously the visibility at places on the leeward side of industrial cities, which

is the east side of many cities in the United States. Locations adjacent to lakes, marshes, and low topography are likely to have frequent radiation and advection fogs. Among the conditions that contribute to the formation of radiation fog in low places are (1) cold dense air drains to low places; (2) further cooling by radiation would result in its reaching the dew point sooner than surrounding areas of warmer air. Advection fog often forms over lake surfaces, especially in the spring and early summer. A shift in the wind direction could result in the fog's being drifted over a near-by airport.



(Courtesy of C.A.A.)

Fig. 149.—A large airport of rectangular shape. The diagonal-lined areas are for automobile parking.

In determining the directions for the principal runways, the prevailing wind directions are considered. In many parts of the United States, the wind prevails from the southwest during the warmer part of the year and from the northwest during the colder months. The prevailing wind direction at some locations is determined by near-by hills and other topography. Rectangular areas might be suitable provided the prevailing winds blow lengthwise of the field. Take-offs are longer and landing speeds greater in thin air, *i.e.*, air of low density. Air density is dependent on barometric pressure and air temperature. The required length of a runway is therefore dependent on the prevailing temperature and pressure conditions. The longest run for a take-

off would be needed when there is no wind, high temperature, and low pressure.

Summary

During and following the First World War, aviation developed rapidly. This development contributed toward, and stimulated the advancement of, meteorology. During those years, meteorological studies were made and new theories advanced. The Norwegian group of scientists did much in the field of meteorology by developing the air-mass and frontal-analysis theory. All this activity in meteorology has helped toward making aviation more efficient and safe. The knowledge of the science of weather not only enables one to understand flying hazards, but it also contributes toward more efficient and pleasant flying.

For the purposes of aviation and forecasting it is essential to identify and understand air-mass types. Also, it is important to be aware of the interaction of air masses with one another and with the earth's surface. These interactions result directly in such phenomena as fog, clouds, precipitation, turbulence, and the many other meteorological conditions which definitely affect flying. Wind directions at the surface of the earth determine in which direction a plane will take off and land. When surface winds are strong and gusty, it is not advisable for small light planes to operate because of the difficulty of controlling them and keeping them from tipping. Wind velocities and directions at flight levels determine the amount of drift to which a plane is subject while in flight. In thin air, an airplane lands and takes off faster, but climbs at a slower rate than it would in air of greater density.

Rough air or turbulence was formerly known as air pockets. It is due to both thermal and so-called mechanical reasons. Updrafts and downdrafts are of vital importance in mountainous regions and may be the cause of much difficulty in landing or taking off in the vicinity of such obstructions as bluffs and hangars. Thunderstorms are phenomena especially associated with cold fronts and in certain air masses. Strong vertical currents are associated with thunderstorms, and they should be avoided by flying around them or by staking down the plane

until they pass on. Hail can very seriously damage the propeller and other parts of a plane. Under certain conditions ice may form on a plane and adversely affect its performance. The pilot must be alert to prevent serious formation of carburetor ice. Such instruments as the air-speed indicator and altimeter are affected by pressure and temperature conditions.

In planning a cross-country flight a pilot attempts to take advantage of favoring winds and good-weather areas and to avoid regions where the winds and weather are not favorable. When the visibility is poor and the ceiling is low, flights are made with the aid of various instruments. Contact flights are indicated when visibilities and ceilings are suitable. In the execution of military and naval aviation operations, weather conditions are as important as in any other type of flying.

Questions

1. In the classification of air masses, what word does the letter "k" represent?

2. What type of clouds are commonly associated with warm fronts?

3. Mention another name often applied to a cold front.

4. Which ordinarily moves the faster, the warm or cold front?

5. What weather element is usually very significant in locating on a weather map the position of a cold front?

6. Describe typical weather conditions ahead of a warm front.

7. What sort of weather accompanies a cold front?

8. Is the weather behind a cold front warmer or colder than that ahead of the front?

9. In a low-pressure region which part is often associated with thunderstorm activity?

10. In their movements across the United States from west to east, what is the average speed of the centers of low-pressure areas?

11. Discuss bombing upwind and downwind.

12. What weather conditions are satisfactory for low-altitude bombing?

13. Discuss bombing when conducted under conditions of dense fog.

14. Discuss weather conditions in which carburetor icing may be expected.

15. What is the cause of carburetor icing?

16. Assume that the altimeter is set to read zero at the surface. If the air temperature is colder than the standard temperature, at an

elevation of 3,000 feet will the altimeter read more than 3,000 feet or less?

17. Suppose that the altimeter is set at zero at the time the plane is hangared for the night. If a low-pressure area moves into the locality, will the altimeter overread or underread the next morning?

18. Does the air-speed indicator show the actual air speed at all levels?

19. If an airplane stalls at an indicated air speed of 40 miles per hour at sea level, what would be the indicated stalling speed at an elevation of 5,000 feet?

20. What weather conditions are associated with the formation of ice on an airplane?

21. Describe what you would do if you notice ice start to form on the plane.

22. Is it possible for water droplets to remain unfrozen in air the temperature of which is below freezing?

23. Why is it necessary that the pilot know the wind direction at various elevations?

24. What effect do gusts have on taking off or landing an airplane?

25. Explain the problem that confronts a pilot when approaching a mountain on the downwind side.

26. In finding a suitable location for an airport what features of climate would be considered?

27. Under which conditions would an airplane make the longer run before taking off, at Denver on a warm day or at La Guardia Field on a cold day?

28. Why are thunderstorms dangerous in which to fly?

29. If you approach a thunderstorm from the south, would you fly to the right or to the left of it?

30. What would you do if you were flying west and were confronted with a cold front along which was a continuous string of energetic thunderstorms?

31. What is the cause of bumpiness?

32. Assume that you are flying across a lake on a bright summer day. Would you experience a bump or a drop as you cross the shore line?

33. Describe an air mass that often exists in the warm sector of a low.

34. What is an occlusion?

35. What sort of flying weather would you expect to find in an air mass west of a cold front?

36. Describe the conditions that favor soaring.

37. Which ride would be the smoothest, when flying under stratus clouds or under cumulus clouds?

38. When flying between clouds, how far must a pilot remain from the edge of a cloud?

39. Why do fronts offer unfavorable weather conditions for flying?

40. Why is it considered impractical to fly over a thunderstorm rather than around it?

41. Which condition would offer the poorest conditions of visibility, a moderate rain or a moderate snow?

42. If you were flying "contact" on a cross-country trip, what would you do if weather conditions became poor enough to require the use of instruments?

43. What part of the year, and during what time of the day, are thunderstorms most common?

44. What wind velocity is associated with the formation of ground fog?

45. In attempting to anticipate the formation of ground fog, of what significance are the temperature and dew-point reports?

46. Why is ice dangerous when it forms on an airplane?

47. Why is it dangerous to attempt a take-off in strong wind conditions?

Suggested Activities

1. Examine closely an instrument panel in the cockpit of a light airplane. Note the arrangement of the instruments on the panel, and determine how each is installed and functions.

2. Make a sketch of an airport in your vicinity. Show the locations of runways, buildings, and obstructions, and indicate the direction of the city, hills, and near-by lakes. Describe the favorable and unfavorable climatic features of the airport's location.

3. Make a list of things relating to weather conditions which in the interest of safety you think should be made the subject of Federal regulation; no doubt many of your suggestions have been enacted into law.

4. Examine carefully a weather map. Write an explanation concerning the reasons for locating fronts where they are, and show why the air masses were identified as indicated.

5. List several types of clouds, and describe the weather conditions you would expect to encounter when they are present.

6. Plan a cross-country trip to be made by airplane. List the weather conditions in which you would be interested, and show what effect they would have on the instruments, your airplane, and the trip.

7. List weather conditions that would likely be encountered during two cross-country trips from east to west, one north of the center of a low, and the other south of the center.

Topics for Class Reports

1. The effect of various weather elements on visibility and ceiling.
2. Weather conditions in military and naval warfare.
3. Flight conditions in winter and in summer in the United States.
4. Planning a small airport.
5. The identification of air masses and fronts, and their relation to flying.
6. The effects of a change in the wind direction during a flight.
7. Observing the weather while making a flight.
8. Visibility at the surface and at flight levels.
9. The heights of clouds.

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Appendix A. The Seasons

The earth rotates on its axis once every day (24 hours) and revolves around the sun once each year ($365\frac{1}{4}$ days). The earth's axis is inclined $23\frac{1}{2}°$ toward the plane of the earth's orbit and always in the same direction, the North Pole pointing toward the North Star (Chap. I). This means that the position of the axis at any given time is parallel to the position at all other times of the year. This inclination and parallelism of the axis and the earth's revolution around the sun are responsible for the following:

1. The migration of the vertical rays of the sun $23\frac{1}{2}°$N. and $23\frac{1}{2}°$S. of the equator
2. A day-to-day change in sun altitude everywhere
3. Differences in the length of day and night

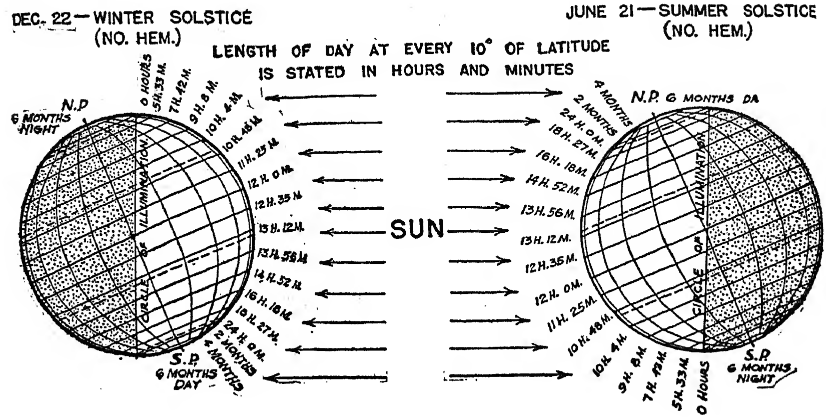
These three factors combine to produce the change of seasons. If the axis were not inclined but were perpendicular to the plane of the earth's orbit, there would be no change of seasons on the earth, and the vertical rays of the sun would remain constantly at the equator. If the axis were inclined more than $23\frac{1}{2}°$, the change of seasons would be somewhat more extreme than at present.

The migration of the vertical rays of the sun over 47° of latitude twice each year makes it possible to determine four important dates. They are:

1. The *equinoxes*—the two days on which the vertical rays of the sun cross the equator
2. The *solstices*—the two days on which the vertical rays reach their greatest distance from the equator

Twice each year the sun's noon rays are vertical at the equator (sun altitude 90°), once on March 21, called the *vernal equinox,* and again on September 22, called the *autumnal equinox* (Fig. 147). The time interval between equinoxes is exactly the same, but the dates fall on different days of the month (21, 22, 23) because of irregularities in the calendar now in use. Since the vertical noon rays strike the equator, the circle of illumination passes through both poles and cuts all the earth's parallels exactly in half. One half of each parallel (180°) is in light; the other half, in darkness. Consequently all places on the earth have equal day, 12 hours, and equal night, 12 hours. (*Equi-nox* means "equal night.") The tangent rays, where sun altitude is zero, touch the poles. Maximum solar energy is being received at the

equator and diminishes regularly toward either pole. Seasons in the north and south intermediate (or temperate) zones are reversed. This means that on March 21, for example, the season in the United States is spring and in Argentina autumn.



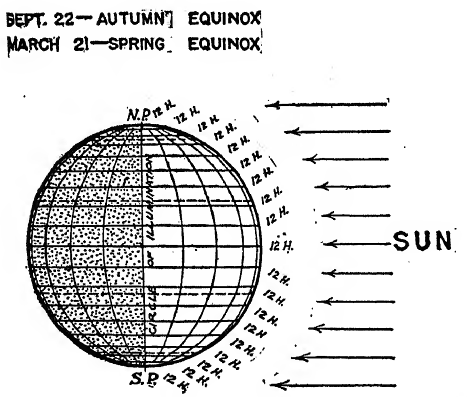


FIG. 150.—On the equinoxes, when the sun's vertical rays are at the equator, the circle of illumination cuts all the parallels in half, and days and nights are equal in length over the entire earth. At this time insolation decreases regularly from equator to poles. At the times of the solstices, the sun's vertical rays have reached their greatest poleward migration. The circle of illumination cuts all the parallels (except the equator) unequally, so that days and nights are unequal in length except at latitude 0°.

After March 21 the vertical rays continue northward in the Northern Hemisphere. On June 21, called the *summer solstice*, the earth is approximately midway in its orbit between the equinoctial positions, and the North Pole is inclined $23\frac{1}{2}°$ toward the sun (Fig. 150). The vertical rays of the sun travel the same number of degrees from the equator as the earth's axis is inclined. Thus on June 21 the vertical rays have reached their farthest point north, touching the parallel $23\frac{1}{2}°$N. which is called the *Tropic of Cancer*. The tangent rays in the Northern Hemisphere pass over the pole and reach the *Arctic Circle*, $66\frac{1}{2}°$N. In the Southern Hemisphere the tangent rays do not reach the pole but terminate at the *Antarctic Circle*, $66\frac{1}{2}°$S. Both Arctic and Antarctic

Circles are 23½° from their respective poles. All parts of the earth north of the Arctic Circle have constant daylight; south of the Antarctic Circle June 21, constant darkness. All parallels, except the equator, are cut unequally by the circle of illumination, those in the Northern Hemisphere having their larger parts toward the sun so that days are longer than nights. Longer days, plus a greater angle of the sun's rays, result in a maximum receipt of solar energy in the Northern Hemisphere, and a summer season is the result. In the Southern Hemisphere at this same time all these conditions are reversed, nights being longer than days, and the sun's rays relatively oblique (low sun altitude), so that receipts of solar radiation are at a minimum, and winter conditions prevail.

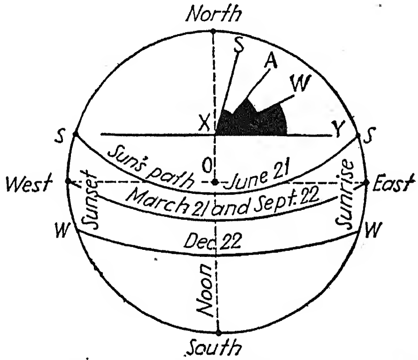


FIG. 151.—The sun's path across the sky at different seasons is shown as it appears to an observer *O* somewhere near the latitude of Philadelphia, Springfield, Ill., or Denver. Only on the equinox does the sun rise due east and set due west. In summer it rises in the northeast and sets in the northwest. In winter it rises in the southeast and sets in the southwest. On all days of the year it is south of the observer at noon. Note how the angle of the sun's rays (sun altitude) at noon decreases from summer to winter. In summer it is represented by the angle *SXY* (about 74°); in autumn and spring by *AXY* (about 50°); and in winter by *WXY* (about 26°). In general the lower the sun altitude the lower the temperature.

On December 22, called the *winter solstice*, when the earth is in the opposite position in its orbit from what it was on June 21, it is the South Pole that is inclined 23½° toward the sun (Fig. 150). The sun's noon rays are then vertical over the *Tropic of Capricorn* (23½°S.), and the tangent rays pass 23½° over the South Pole to the Antarctic Circle (66½°S.). Consequently south of 66½°S. there is constant light, and north of 66½°N. there is a continuous absence of sunlight. All parallels of the earth, except the equator, are cut unequally by the circle of illumination, with days longer and the sun's rays more nearly vertical in the Southern Hemisphere. This, therefore, is summer south of the equator but winter in the Northern Hemisphere where opposite conditions prevail.

Because of the inclination of the earth's axis, the path of the sun across the sky during the day varies greatly in different parts of the world. At the equator, at the time of an equinox, the sun rises due east, is directly overhead at noon, and sets due west. Dawn and twilight are of much shorter duration than in middle or high latitudes. On June 21 at the equator the sun rises north of east, is north at noon, and sets north of west; on December 22 it rises south of east, is south at noon, and sets south of west.

In the Northern Hemisphere, north of the Tropic of Cancer, the path of the sun is entirely unlike that in the vicinity of the equator. Since the Tropic

of Cancer is everywhere south of the United States, the noon sun is always south and never is directly overhead at any point in this country. However, at Key West, Fla., the southernmost point in the United States, the noon sun is extremely close to a vertical position on June 21. On this same date much of the country has 14 to 15 hours of sunlight, the sun swinging in a large arc across the sky, rising in the northeast, being south at noon, and setting in the northwest (Fig. 151). In Canada the hours of sunlight on June 21 vary from 16 to 24, depending upon nearness to the Arctic Circle. The farther north the longer the day. On the west shore of Lake Winnipeg is a summer resort where, especially in June and July, the long days are very noticeable and where by August the growth of grasses, bushes, and vines is so thick that it is almost impossible to see from one cabin to another. The rapid growth of vegetation during the summer is due in part to the long days. The path of the sun on the north coast of Alaska on June 21 is interesting. Barring clouds, the sun appears in the east in the morning, south at noon, west in the evening, and north at midnight, thus swinging around the observer in a huge circle, being highest above the horizon at noon and lowest at midnight. On this same date Little America in Antarctica experiences continuous darkness.

Appendix B

Supplementary Climatic Data for Selected Stations

(T., temperature in degrees Fahrenheit; Rf., rainfall in inches)

		Jan.	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Year*	*Range*
1.	T.	79	79	80	81	81	80	81	82	83	83	82	81	81	4.0
	Rf.	7.9	4.6	7.2	6.0	11.1	11.7	9.9	6.5	3.1	2.9	6.7	11.1	88.7	
2.	T.	80	80	82	83	83	82	81	81	81	81	80	80	81	3.2
	Rf.	3.3	1.9	4.3	9.7	10.9	7.3	4.4	3.2	4.8	13.4	11.8	5.1	80.1	
3.	T.	80	79	80	80	80	80	80	79	80	79	79	80	80	1.1
	Rf.	3.9	1.7	1.7	4.2	12.6	13.5	16.2	14.9	12.5	14.8	21.5	11.9	129.4	
4.	T.	79	81	84	86	84	82	82	82	82	81	80	79	82	7.0
	Rf.	0.9	0.1	0.3	1.7	8.3	12.6	11.1	11.0	13.3	11.1	3.7	3.1	77.2	
5.	T.	84	83	84	84	82	79	77	80	83	86	86	85	83	8.5
	Rf.	15.3	13.0	9.7	4.5	0.7	0.2	0.1	0.1	0.5	2.1	5.2	10.3	61.7	
6.	T.	70	75	83	90	89	87	87	86	85	83	76	71	82	20
	Rf.	0.1	0.1	0.2	1.1	5.8	5.5	3.3	4.6	5.7	4.7	1.6	0.4	35.1	
7.	T.	60	62	65	64	66	64	62	61	61	62	59	59	62	7
	Rf.	0.6	1.9	2.8	3.4	3.0	5.7	11.0	12.1	7.6	0.8	0.5	0.2	49.6	
8.	T.	49	54	61	71	81	90	95	94	88	80	63	53	73	46
	Rf.	1.2	1.3	1.3	0.9	0.2	0.0	0.0	0.0	0.0	0.1	0.8	1.2	7.0	
9.	T.	60	60	59	58	57	55	55	54	55	58	59	60	58	6
	Rf.	0.0	0.1	0.2	0.2	0.4	0.3	0.2	0.4	0.3	0.0	0.2	0.1	2.3	
10.	T.	58	62	68	73	79	82	82	83	78	71	64	57	71	25.2
	Rf.	0.5	0.5	0.7	1.1	1.2	2.3	2.1	2.0	4.4	2.4	1.3	1.0	19.5	
11.	T.	19	23	33	48	64	73	76	74	63	50	36	27	49	56.9
	Rf.	0.5	0.4	0.4	0.7	0.7	0.8	0.5	0.5	0.5	0.5	0.5	0.6	6.6	
12.	T.	74	74	70	64	58	54	52	54	57	62	67	71	63	22.4
	Rf.	0.7	0.6	1.0	1.7	2.8	3.1	2.6	2.5	2.0	1.7	1.2	1.0	20.9	
13.	T.	70	70	68	63	59	56	55	56	58	61	64	68	62	15.6
	Rf.	0.7	0.6	0.9	1.9	3.8	4.5	3.6	3.4	2.3	1.6	1.1	0.8	25.2	
14.	T.	49	50	53	56	61	68	73	75	70	64	57	52	61	25.4
	Rf.	4.0	2.6	3.3	2.0	1.7	0.7	0.1	0.1	1.1	3.4	4.1	3.9	27.0	
15.	T.	74	73	69	61	55	50	49	51	55	60	66	71	61	24.7
	Rf.	3.1	2.7	4.4	3.5	2.9	2.5	2.2	2.5	3.0	3.5	3.1	3.9	37.3	
16.	T.	53	55	63	69	75	81	83	83	79	70	61	54	69	30.6
	Rf.	1.4	1.6	1.8	2.7	3.2	2.7	2.5	2.6	3.5	2.0	2.2	1.8	28.0	
17.	T.	77	77	76	72	68	65	65	66	68	70	73	75	71	12
	Rf.	4.6	4.5	4.6	3.0	2.0	0.7	0.8	2.0	3.7	4.9	4.4	4.5	39.7	

Supplementary Climatic Data for Selected Stations.—(*Continued*)

(T., temperature in degrees Fahrenheit; Rf., rainfall in inches)

	Jan.	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Year*	*Range*
18. T.	34	34	35	42	49	55	58	53	53	45	39	35	45	24.3
Rf.	8.5	6.4	5.9	4.1	4.5	3.8	5.8	7.5	8.7	8.9	8.3	8.5	81.0	
19. T.	62	60	58	53	50	46	46	46	48	52	55	59	53	16.4
Rf.	2.4	3.0	5.5	9.4	15.2	17.0	16.1	13.2	8.7	5.2	5.0	4.1	104.8	
20. T.	39	40	43	48	53	57	60	60	56	50	45	42	49	21.1
Rf.	4.5	3.5	2.5	1.7	1.3	0.9	0.4	0.6	2.0	2.5	6.5	5.9	32.5	
21. T.	22	25	37	51	63	72	77	75	66	55	39	27	51	55
Rf.	0.7	0.9	1.3	2.8	4.1	4.7	4.0	3.2	3.0	2.3	1.1	0.9	29.0	
22. T.	32	38	46	55	63	70	75	73	66	56	44	36	55	42
Rf.	2.4	2.3	2.7	3.4	4.1	3.3	2.0	2.2	3.5	4.7	4.3	3.0	39.8	
23. T.	8	14	30	47	60	71	77	75	61	43	29	14	44	68.4
Rf.	0.2	0.3	0.7	1.1	2.2	3.4	5.8	5.3	3.3	1.5	0.9	0.2	24.9	
24. T.	− 4	0	15	38	52	62	60	64	54	41	21	6	35	70
Rf.	0.9	0.7	1.2	1.4	2.0	3.1	3.1	2.2	2.2	1.4	1.1	0.9	20.2	
25. T.	24	23	27	38	49	57	62	59	50	41	32	25	41	39
Rf.	1.3	1.1	1.2	1.2	1.7	2.0	2.7	2.8	2.0	2.1	1.7	1.6	21.4	
26. T.	− 3	2	13	30	47	59	64	59	48	32	13	2	31	66.9
Rf.	1.1	0.8	0.8	0.7	1.5	2.7	3.0	2.3	1.4	2.4	1.4	1.9	20.0	
27. T.	24	24	32	40	49	58	65	65	59	49	40	29	44	44.7
Rf.	6.0	4.7	5.1	4.6	3.8	3.8	3.7	4.6	4.1	5.5	5.9	5.5	57.3	
28. T.	8	9	18	30	41	53	60	56	46	34	22	12	33	52
Rf.	0.9	0.7	0.8	0.7	1.2	1.8	2.4	2.4	2.2	1.6	1.2	0.9	16.8	
29. T.	−23	−11	4	29	46	57	59	54	42	25	1	−13	23	82.4
Rf.	0.8	0.8	0.5	0.7	0.9	1.3	1.6	1.6	1.7	1.3	1.3	1.1	13.6	
30. T.	4	− 2	− 2	8	23	35	42	40	32	22	11	6	18	44
Rf.	1.4	1.3	1.1	0.9	0.5	0.4	0.6	0.6	1.0	1.2	1.0	1.5	11.8	

Stations for which data are given above:

1. Georgetown, British Guiana
2. Colombo, Ceylon
3. Colón, Canal Zone
4. Saïgon, French Indochina
5. Darwin, Australia
6. Mandalay, Burma
7. Addis Ababa, Ethiopia
8. Baghdad, Iraq
9. Port Nolloth, Union of South Africa
10. Monterrey, Mex.
11. Astrakhan, U.S.S.R.
12. Adelaide, Australia
13. Capetown, Union of South Africa
14. Algers (Algiers), Algeria
15. Buenos Aires, Argentina
16. San Antonio, Tex.
17. Durban, South Africa
18. Bergen, Norway
19. Valdivia, Chile
20. Victoria, Can.
21. Omaha, Neb.
22. Milano (Milan), Italy
23. Mukden, Manchuria
24. Winnipeg, Can.
25. Uppsala, Sweden
26. Tomsk, U.S.S.R. (Siberia)
27. Halifax, Can.
28. Arkhangelsk (Archangel), U.S.S.R.
29. Dawson, Can.
30. Spitsbergen

Appendix C. Meteorological Instruments and the Weather Map

In the study of the atmosphere it is desirable that at least a few weather instruments be available for daily observation. A complete set of meteorological instruments of the best kind is very expensive, yet a few essential ones may be purchased at reasonable cost. These should be housed in a case built outside one window of the laboratory. It should have a glass door facing the window, and the other three sides should be sufficiently open to allow free circulation of the air. At very small cost, bulletins may be secured from the U.S. Weather Bureau describing instrument cases and instrument installation. Teachers and interested students should secure the list of publications for sale by the Weather Bureau. It is sent free.

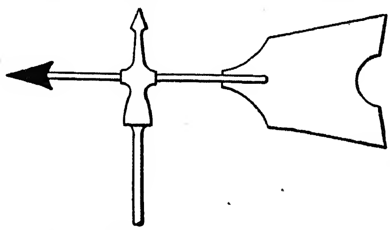


FIG. 152.—The wind vane points toward the direction from which the wind is blowing.

The two most essential instruments needed to forecast the weather are the *barograph* and the *wind vane*. A barograph is cheaper than a mercury barometer. It traces a curve on graph paper showing changes in air pressure. One needs simply to glance at the curve to note whether the barometer is rising or falling. Much cheaper than a barograph is the *aneroid barometer*, which, if used in forecasting, requires that the observer record the reading at least every 30 minutes in order to note changes in pressure. The wind vane is a simple arrow, free to rotate as the wind changes direction (Fig. 152). It can be made in any workshop. Metal vanes are more durable than wood. Aluminum paint is recommended. The vane should be placed on top of some building where it is visible from the laboratory. It needs to be emphasized that the arrow points *toward* the direction *from which* the wind is blowing.

MEASURING TEMPERATURE

A great many thermometers employ mercury as an indicating medium. Like most metals, mercury expands when temperature rises and contracts when temperature drops. Some thermometers make use of clear or colored alcohol which has the advantage of having a much lower freezing point than mercury.

The two temperature scales most used are the *Fahrenheit* and the *centigrade.* On the Fahrenheit the freezing point of water is 32° and the boiling point 212°; on the centigrade the freezing point is 0° and the boiling point is 100°. Thermometers used to record air temperature should never be exposed to the direct rays of the sun.

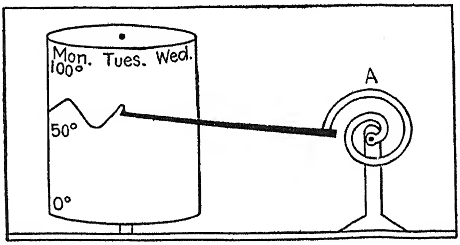


FIG. 153.—The thermograph. Clockworks inside the cylinder cause it to revolve once a week. Expansion and contraction of the sensitive metallic coil *A* is such that the temperature indicated by the pen point corresponds to the reading of a thermometer.

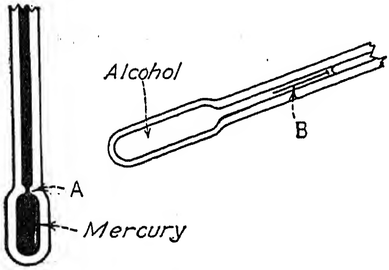


FIG. 154.—Maximum and minimum thermometers. In the maximum thermometer a constriction *A* above the bulb permits the mercury to rise in the capillary tube but does not allow it to return except when the thermometer is given a vigorous shaking. The minimum thermometer uses clear alcohol and must be placed at an angle of about 20°. The black float *B* is pulled downhill to the lowest temperature of the day by two forces: the surface tension of the top of the alcohol column and the force of gravity.

The *thermograph* is an instrument that records air temperature on graph paper. These instruments are of several designs. One consists of a cylinder made to revolve once each week by means of clockworks inside (Fig. 153). A sheet of graph paper is fastened on the outside. A pen point that rests on the paper traces the temperature curve.

A *maximum thermometer* is one in which the mercury rises to the highest temperature of the day and remains there (Fig. 154). This thermometer also is used by doctors when taking the temperature of the human body.

The *minimum thermometer,* which employs clear alcohol and a tiny black float, records the lowest temperature of the day (Fig. 154).

MEASURING ATMOSPHERIC PRESSURE

A simple *mercury barometer* is made by filling a glass tube about 32 inches long with mercury and inverting it so that the open end of the tube is below the surface of mercury in a dish of some kind (Fig. 155). The mercury column at sea level will be about 30 inches high and is equivalent to a pressure of about 15 pounds per square inch. For several thousand feet above sea level, the column decreases about 1 inch in height for each 900 feet increase in elevation. As storms come and go, the weight or pressure of the atmosphere

upon the surface of the mercury in the dish changes, and this causes the top of the column of mercury to rise and fall. Over most of the United States a falling barometer, accompanied by winds from the northeast, east, or southeast, indicates the approach of unsettled weather. A rising barometer with winds from the southwest, west, or northwest usually foretells fair weather. An accurate mercury barometer is quite expensive.

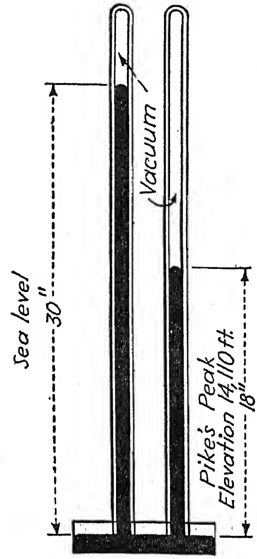


FIG. 155.—The mercury barometer. At sea level, atmospheric pressure (or weight) is sufficient to balance the weight of a column of mercury about 30 inches high. As elevation above sea level increases, atmospheric pressure decreases.

An *aneroid barometer* is made by exhausting the air from a thin, circular, metallic box (Fig. 156). With practically no air pressure on the inside and 15 pounds (or less) per square inch on the outside, it is evident that the box would collapse were it not for a strong spring inside. If one side of the box is made immovable, the other side will move owing to changes in atmospheric pressure. The surface of the metallic box is corrugated to increase the area exposed to the air. The movement of the spring causes an indicating arm, or pointer, to move over a scale of figures corresponding to the readings of a mercury barometer. Since air pressure decreases rather regularly with increase in altitude, the aneroid is used to make *altimeters* (Fig. 157). On the altimeter the indicating arm moves over a scale marked off in hundreds and thousands of feet above sea level. Good aneroids, to be used for noting changes in air pressure caused by the passing of storms, vary in price.

The *barograph* is an instrument that records atmospheric pressure on graph paper (Fig. 158). As in the case of the thermograph, the paper is fastened on the outside of the cylinder. Clockworks inside the cylinder cause it to

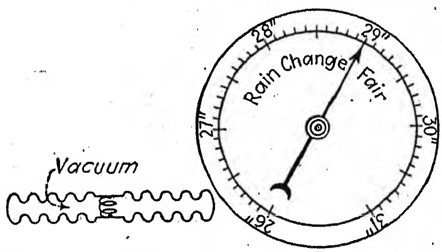


FIG. 156.—The aneroid barometer. A cross section of the circular metallic vacuum box with spring inside is shown. The walls of this box move slightly as changes in atmospheric pressure occur. This movement is transferred to an indicating arm which in turn moves over a set of figures on the face of the dial. The words "rain," "change," and "fair" cannot be used unless they are set for the elevation above sea level where the instrument is to be used.

rotate once a week. The pen point that traces the pressure curve on the paper is made to move up (rising barometer) or down (falling barometer) by means of a series of levers attached to a compound aneroid. The several aneroids in tandem provide a more pronounced response to changes in atmospheric pressure than would be indicated by a single aneroid of the same size. As stated previously, this instrument clearly shows the changes that are taking place in air pressure, and these changes often indicate the nature of weather to be expected

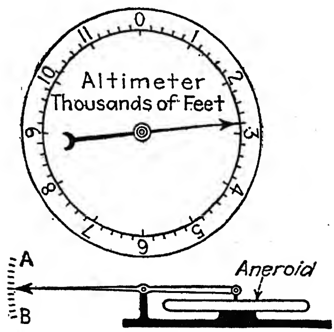


FIG. 157.—The altimeter. In the lower figure, will the pointer move toward *A* or *B* when altitude increases? Why? It should be remembered that changes in atmospheric pressure due to the passing of storms may cause considerable error in the altimeter reading. This is another reason why airplane pilots must be familiar with the weather map.

WIND VELOCITY

Wind velocity may be gauged to some extent by several methods. If the leaves on a tree are perfectly quiet, a *calm* prevails. A *strong* wind will cause tree branches to move noticeably. Winds of *gale* or *hurricane* velocity usually do considerable damage. If a small airplane propeller is fastened to the pointed end of the wind vane, some idea of wind velocity may be obtained by observing the speed at which the propeller turns.

Weather bureaus and aviation companies ascertain accurate wind velocities by means of the *anemometer* (Fig. 159). This instrument consists of three

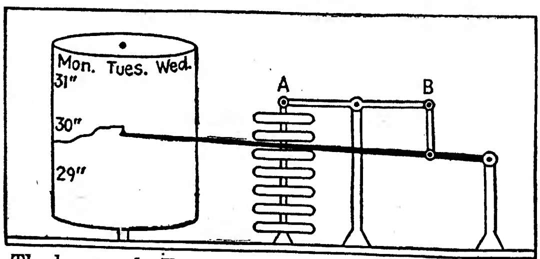


FIG. 158.—The barograph. To the right of the revolving cylinder is a compound aneroid (seven aneroids in tandem). When pressure increases, the compound aneroid is compressed, point *A* moves down, and point *B* moves up. Since *B* is connected to the pointer, the pen point moves up to record higher pressure. When pressure decreases, each of the seven aneroid springs opens slightly, causing point *A* to move up and *B* down. The levers are adjusted so that the pressure recorded by the pen will correspond with the reading of a mercury barometer.

(sometimes four) revolving cups. The stronger the wind the faster the cups will rotate. This rotation operates a complex set of gears which in turn indicates the wind velocity in miles per hour. As might be expected, an anemometer is an expensive instrument. Mechanically inclined students can build a home-

made anemometer of rough design. Three or four aluminum cups can be fastened to an upright arm pivoted at each end so that it turns easily. An electrical switch can be arranged at the bottom of the arm so that each time the cups rotate once an electrical circuit is closed, which will cause a small light in the laboratory to flash. By counting the flashes per minute, some idea of wind velocity is obtained.

The so-called "Beaufort Scale" of wind velocities was devised by Admiral Sir Francis Beaufort of the British Navy in 1805. It is a useful method of estimating wind velocities, and is given in condensed form below.

BEAUFORT SCALE OF WIND VELOCITY (Complete Table on Page 223)

Name	*Miles per Hour*	*Indicated by*
Calm	Less than 1	Tree leaves quiet. Smoke rises vertically.
Light breeze	1– 7	Leaves rustle.
Gentle breeze	8–12	Leaves and twigs in constant motion.
Moderate breeze	13–18	Raises dust. Small branches move.
Fresh breeze	19–24	Small trees in leaf begin to sway.
Strong wind	25–38	Large branches and whole trees in motion.
Gale	39–54	Tree limbs break.
Whole gale	55–75	Trees uprooted. Seldom experienced inland.
Hurricane	Above 75	Extremely destructive.

MEASURING HUMIDITY

Instruments used to determine the relative humidity of the air are called *hygrometers*. Three types will be mentioned here. They are (1) the wet- and dry-bulb hygrometer, (2) the hair hygrometer, and (3) the hygrograph.

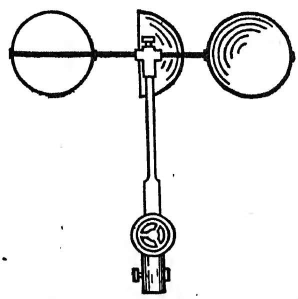


FIG. 159.—The anemometer (three cup) which measures the velocity of the wind in miles per hour.

The *wet- and dry-bulb hygrometer* provides the easiest and most accurate method of determining relative humidity. One good thermometer is all that is necessary. First the temperature of the air as shown by the thermometer is noted. Next, a piece of fine, loosely woven muslin is tied around the bulb and moistened. Then the instrument is fanned vigorously. Evaporation of water from the cloth will cause the temperature to drop. The drier the air (low relative humidity) the lower the thermometer will read. Subtract the two temperatures to get the difference between the wet- and dry-bulb readings. Now refer to the chart that accompanies the exercise on humidity in the laboratory manual. Using the figures already obtained and following the simple instructions that accompany the chart, the relative humidity can be determined.

Once the relative humidity is known, it is an easy matter to determine the absolute humidity and the dew point. Studies are being made of temperature and dew-point data in an effort to ascertain those conditions of the atmosphere which are most likely to cause icing of airplanes.

The *sling psychrometer* consists of a metal strip to which two thermometers are securely fastened. One thermometer bulb is covered with a cloth which can be moistened when making a test. The upper end of the metal strip is fastened to a handle in such a way that the two thermometers can be whirled around at a rapid rate. The rotary motion is continued until the wet-bulb temperature ceases to drop. Then the two thermometers are read, and reference is made to the relative humidity chart as explained for the wet- and dry-bulb hygrometer. Official Weather Bureau tests for humidity are made by the whirling wet- and dry-bulb method.

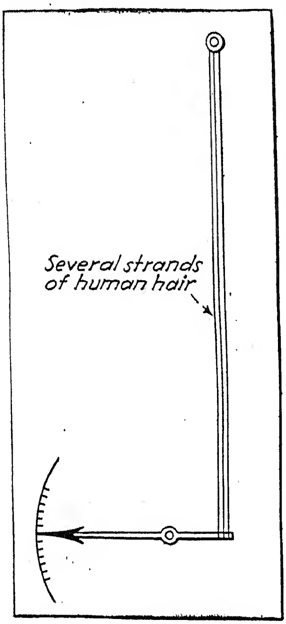


FIG. 160.—Hair hygrometer (much simplified). As relative humidity varies, the length of the human hair changes, causing an indicating arm to move over a scale of figures reading from 0 to 100 per cent.

The *hair hygrometer* is less accurate than the wet- and dry-bulb method. Human hair, from which the oil has been removed by using ether, becomes longer as the relative humidity of the air increases. This change can be made to move an indicating needle which moves over a scale, the graduations of which read from 0 to 100 per cent (Fig. 160). Exposure to the air causes the hair to become dirty and perhaps greasy, thus decreasing the accuracy of the instrument. The hair must be cleaned occasionally with ether or other suitable solvent.

The *hygrograph,* which is a form of hair hygrometer, is an instrument that records relative humidity on graph paper. As with the thermograph and barograph, a sheet of graph paper is fastened on the outside of a cylinder which rotates once each week. The pen point that traces the relative humidity curve on the graph paper is made to move up and down by an arrangement of levers fastened to several strands of human hair.

Some self-recording instruments are extremely sensitive to quick changes in meteorological conditions. Let us suppose that a warm, moist south wind is blowing and that there is an instantaneous change to a cold northwest wind. The thermograph curve may drop vertically 15° or 20°; the barograph curve will show a sharp increase in pressure; and the hygrograph reading may drop 30 per cent or more.

Measuring Precipitation

Precipitation may fall in the form of rain, snow, sleet, or hail. In case it falls in the solid form, it is melted, and the water is measured in a standard

rain gauge. Ordinarily, 8 to 12 inches of snow will equal 1 inch of rain. The rain gauge consists of a galvanized-iron cylinder 8 inches (sometimes 12) in diameter and about a foot deep. The bottom of the cylinder is funnel shaped with a small opening to allow the water to be drawn off. In order to measure small amounts of rain, the water from the large cylinder runs into a smaller cylinder (Fig. 161). Thus water that is 1 inch deep in the large cylinder is "stretched out" in the small cylinder to a length sufficient for graduations of $\frac{1}{100}$ inch to be shown.

Depth of snow may be measured by an ordinary yardstick on level ground where no drifting has occurred. A snow gauge may be constructed of an upright galvanized cylinder, about 6 inches in diameter and 3 feet deep. All rain and snow gauges must be so exposed that buildings and trees do not interfere with the fall of precipitation.

Electrical devices for recording rainfall may be observed at most weather bureaus. A sheet of graph paper is placed on the outside of a cylinder which rotates once every 12 hours (instead of once a week, as with the thermograph, barograph, and hygrograph). The more rapid rotation is necessary in order to record extremely heavy rains. A pen point resting on the graph paper records each $\frac{1}{100}$ inch of rain at the time it falls.

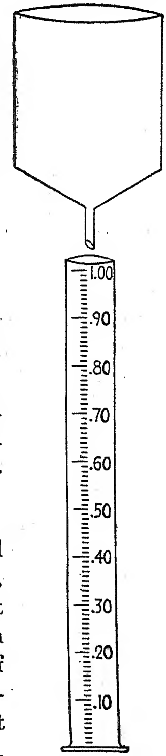


FIG. 161.—Rain gauge. In the large funnel 1 inch of water is "stretched out" in the graduated cylinder so that $\frac{1}{100}$ inch of rain can be measured.

OTHER WEATHER DATA

The *cloud ceiling* is the altitude of the bottom of a cloud layer. Low ceilings, characteristic especially of stratus clouds, constitute one of the greatest hazards in aviation. The height of the ceiling is ascertained by releasing a rubber balloon about $2\frac{1}{2}$ feet in diameter filled with a definite amount of hydrogen. Its ascent is watched carefully through a telescopic instrument called a *theodolite*. The balloon rises about 600 feet per minute. If it disappears in the clouds in 3 minutes, it is evident that the ceiling is about 1,800 feet. On clear days the balloon may be observed for a considerable length of time. Its path enables the meteorologist to determine the direction and velocity of winds aloft.

Upper air data are obtained by *meteorographs* carried aloft by airplanes. The meteorograph records temperature, pressure, and relative humidity during the entire flight. The *radio-meteorograph* has been developed. It consists of a radio transmitting unit, a battery unit, and a meteorograph. When the instrument is carried aloft by a balloon, it automatically broadcasts upper air weather data to a specially designed radio receiving set on the ground. The total weight of some radio-meteorographs is less than two pounds.

THE WEATHER MAP

Four times daily, at 1:30 and 7:30 A.M. and P.M., Eastern Standard time, weather observers at about 250 stations scattered over North America make

careful weather observations. These observations (temperature, pressure precipitation, wind direction and velocity, etc.) are reported by telegraphic code to the U.S Weather Bureau at Washington, D.C., and to regular government weather stations throughout the country. Code is used, because it increases brevity of reports, saves time, and is economical. It is not used for secrecy. At Washington, at district forecast centers, and at local centers, trained men decode the messages and transfer the information to a skeleton map of North America (or the United States). The result is a picture of weather conditions known as the *daily weather map*. Abbreviated and simplified weather maps are published in many daily newspapers.

At the more important weather stations, especially those located on transcontinental air lines, additional weather maps are made at 1:30 A.M. and 1:30 P.M., Eastern Standard time. Along the major transcontinental air lines, weather data are being transmitted and received by teletype machines at all hours of the day and night. This service makes it possible to inform aviators of the sudden changes that often take place in the atmosphere. Such information has to do especially with the location of storm centers and fog, the height of the cloud ceiling, wind direction and velocity, and the degree of visibility at various landing fields along the route.

The weather map is of value in several ways but especially (1) in showing actual weather conditions over the country at the time of observation and (2) in providing the necessary data for making weather forecasts for the next day. Since weather information is valuable in many lines of work, and since the maps are published in many newspapers, a description of the essential features of the weather map will now be considered.

On the large skeleton map used in regular weather bureau offices, the location of the 250 or more weather stations is indicated by open circles. It is customary for one man to decipher the code messages; as he recites the name of a station and its weather data, another man writes the figures on the skeleton map at the correct place. When this is completed for all stations reporting, isobars and isotherms are drawn. An *isobar* is a solid line that passes through places of equal atmospheric pressure. (All pressure readings are reduced to sea level before they are telegraphed from one station to another.) An *isotherm* (dotted line) passes through places of equal temperature. Maps printed in newspapers usually show only the isobars, temperatures being indicated by figures at a number of cities.

By using the circle at a given station the weather conditions at that station are shown by symbols, some of which are as follows:

○ Clear
◑ Partly cloudy
● Cloudy (overcast)
⊗ Sky obscured by fog, snow, or duststorm
⊙ Rain
⊛ Snow
South East wind, gentle
West wind, strong
Thunderstorm

Shaded portions of the weather map indicate those areas where precipitation is occurring.

On some maps, feathers are drawn at the end of the wind arrow, the number of feathers indicating the wind velocity.

When the map is completed, it may be noted that several isobars form rough ovals about a point of low pressure. The word "low" is printed in the center of these ovals. This formation is called a *low-pressure area*, or *cyclone*. If the ovals form about a point of high pressure, the word "high" is printed in the center and an *anticyclone* is indicated. All lows and highs are not to be thought of as cyclones and anticyclones. A well-developed storm (low) usually will have four to ten encircling isobars and will be characterized by precipitation and often rather strong winds.

Warm and cold fronts are indicated by colored lines and the abbreviations of air masses, such as *Tg* (Tropical Gulf) and *Pc* (Polar Continental), are stamped on the map at appropriate places (see pages 119–122).

If the air mass is warmer than the surface over which it is moving, the letter W is added to the air mass symbol; if colder than the surface, the letter K is added.

Charts showing weather symbols may be secured from the U. S. Weather Bureau. Excellent cloud charts also are available.

NOTE: At the present time (1942) war restrictions prohibit weather bureaus from giving detailed daily weather information to the public.

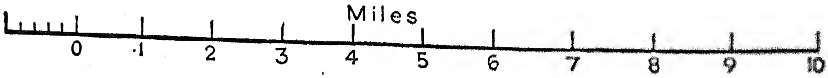
Appendix D. Interpretation of Maps

Maps are graphic representations of the surface of the earth. They are used in many fields of learning but especially in earth sciences. For the student of geography the map is an essential tool, a means of recording facts, and also a manner of expression. Maps are almost infinite in number, size, form, and meaning, and they constitute almost a language in themselves. Some indeed are works of art and demand a high degree of skill in design, construction, and coloring. A person highly trained in the art of map making is called a *cartographer*.

When studying a good map, three essential features should be noted: (1) the scale of the map, (2) the map projection, and (3) the types of things represented on the map and the meanings of the various kinds of symbols or devices used to show them.

The scale of the map may be indicated in one or more ways.

1. By a line graph. Example:



2. By a statement of the proportion used. Example:

1 inch = 50 miles.

3. By a representative fraction. Example:

$$\frac{1}{63{,}360}, \text{ or } 1{:}63{,}360,$$

which means that 1 inch on the map equals 63,360 inches on the earth's surface. Since there are 63,360 inches in 1 mile, this scale also may be written 1 inch = 1 mile. Instead of inches, other units, such as the centimeter, may be used.

A map projection, broadly speaking, is a system of drawing parallels and meridians. Many projections are the result of complicated mathematical computations. True perspective projections may be obtained by casting shadows of parallels and meridians on flat sheets of paper. Imagine a hollow globe the outer shell of which consists of two hemispheres of clear glass. Parallels and meridians are painted on the outside of the glass, and an electric

light is put inside the globe, say at the center. When placed in a dark room, the shadows of the lines, cast on a sheet of paper that is tangent to the globe surface, can be traced. By changing the position of the light or of the sheet of paper or both, different arrangements of parallels and meridians may be secured.

Some map projections are constructed so that they represent the shapes of land areas and seas correctly; others show sizes correctly. It is impossible for any projection that includes a considerable area to accomplish both these objectives. Some accomplish neither. An equal-area map may show certain land and water bodies badly distorted in shape. Likewise, a map that maintains the true shapes of areas may be very misleading if used to compare the sizes of land or sea areas. It is well to remember that *the only true representation of the whole earth is a globe.*

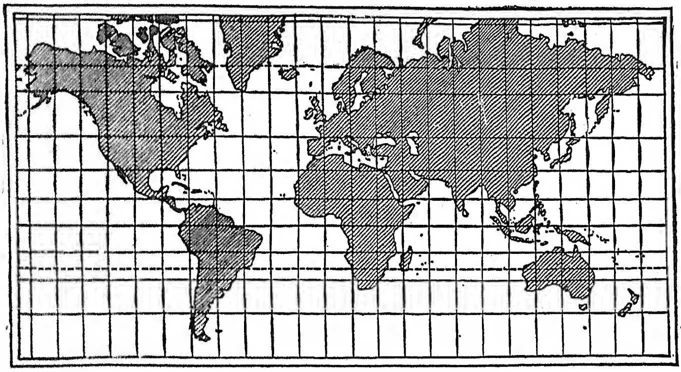


FIG. 162.—Mercator's projection.

Mercator's projection (Fig. 162), which is used for maps of the world, was first published in 1569. In this projection both meridians and parallels are straight lines, always crossing at right angles. The meridians, instead of coming together at the poles, are drawn as parallel lines and thus in high latitudes (from about the 50th parallel to the poles) are much too far apart. To balance this great distortion, the parallels also are spaced much farther apart in high latitudes than near the equator. Thus an area 10° by 10° in Alaska is much larger than one on the equator. A serious objection to the Mercator map (for school use) is that land and water bodies in high latitudes are greatly exaggerated in size. Greenland appears larger than South America when in reality its area is less than that of Argentina. Furthermore, no single scale of miles can be used for all parts of the Mercator map, and it is virtually impossible to show polar regions. Two advantages of this projection should be mentioned. One is the ease of telling the direction from one place to another. This map is especially valuable to navigators because they can draw a straight line from one place to another and thus determine the sailing course. However, the Great Circle route (shortest path) between important seaports is seldom a straight line on the Mercator map. In order to follow the Great Circle the

navigator must make frequent changes in his compass course. A second advantage of this map is that relatively small areas are fairly correct in shape.

Aitoff's projection is representative of several in which the whole earth's surface is shown in an oval (Fig. 163). It is an equal-area projection. Continents near the center of the map are shaped fairly accurately. Toward the east and west margins, however, shapes are badly distorted. Figure 164 is drawn on the interrupted Aitoff projection. This has the advantage of showing correct size and fairly good shape of land and water bodies. It is necessary, of course, for the eye of the observer to bridge the gaps in the grid caused by the interruptions. By reducing ocean areas and shifting the relative location of Australia, the map is given a compact appearance.

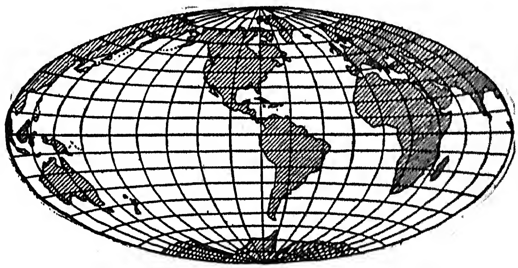


FIG. 163.—Aitoff's projection.

Goode's homolosine projection (Fig. 165) is an equal-area map of the world.[1] Since the interruptions are in the oceans, the continents show clearly and are well shaped. The parallels are straight lines, so that the map is well suited to the study of comparative latitudes. Equal-area projections of the entire earth's surface are of great value for the purpose of showing the world distribution of economic data, climatic regions, or soils. On such maps it is desirable that areas be shown in their true proportion to one another.

The *conical* projection and its modifications are used for maps of continents or smaller areas. To understand the simple form of this projection, imagine a large paper cone set down upon a globe with its apex directly above the pole of the globe. The cone is tangent to the globe along the entire circumference of a selected parallel, which is called the *standard parallel.* Because this parallel is everywhere equally distant from the apex of the cone, it becomes an arc of a circle when the cone is opened out into a plane surface, and all other parallels become arcs of concentric circles (Fig. 166). The meridians are straight lines which radiate from the apex.

Another modification of the conic projection is called the *polyconic* (Fig. 167). It is drawn as if many cones of different taper were fitted upon a globe, each tangent on a different parallel. This projection often is used as a basis of detailed surveys, such as the United States topographic maps or the Inter-

[1] J. Paul Goode, late of the department of geography, the University of Chicago, contributed much to the art of map making in the United States. *Goode's School Atlas* is widely used.

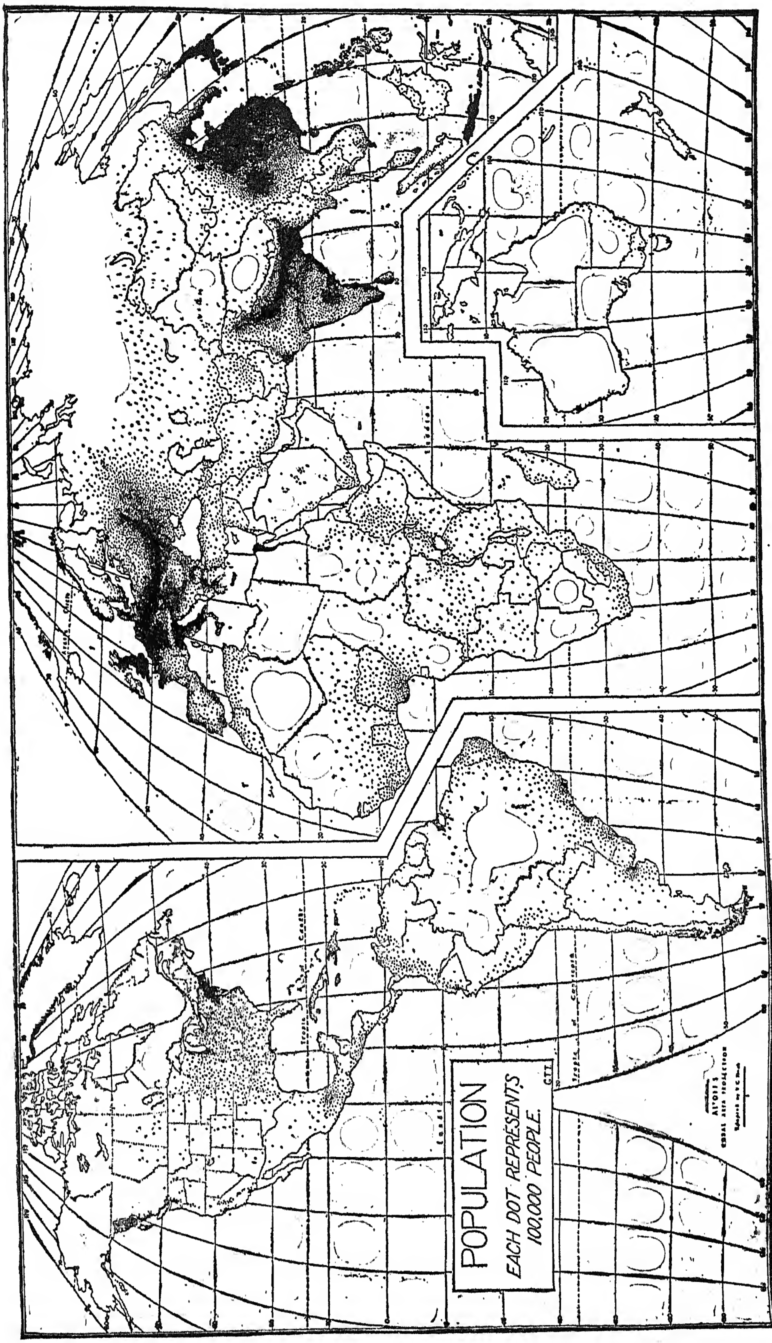


FIG. 164.

national Map of the World on a scale of 1:1,000,000. Many maps of the entire United States are drawn on the polyconic projection. In *Bonne's* projection (Fig. 168) the parallels are concentric circles, but the meridians are curved lines. This produces a grid more like that of a true globe. The great variety of maps that may be seen in a good atlas is a result of the numerous devices that are employed to represent different things. A most useful device is the *dot map* (Fig. 164). Each dot represents a definite number or quantity. Such maps are excellent in providing pictures of the areal distribution of many items such as citrus fruits, corn, or beef cattle. Round dots, triangles, or squares may be used. Maps having devices of this kind are called *cartograms*.

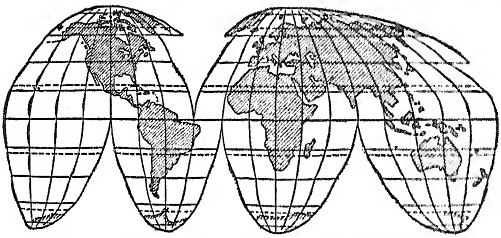


FIG. 165.—Goode's homolosine projection.

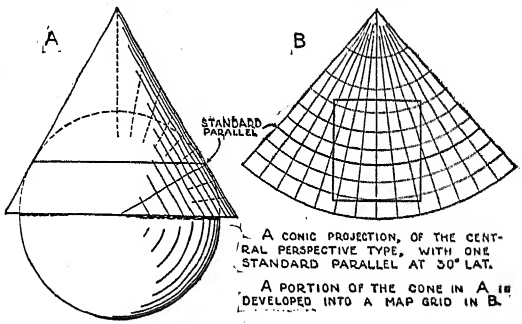


FIG. 166.

The dot map is properly effective only when shown on an equal-area projection. On some maps, dots or squares of different sizes are given graduated values. These are of particular value in showing the concentration of production, industry, or mineral wealth in certain localities (Fig. 169).

Other useful maps are made in different ways. A *political map* is one on which different colors are used for different countries, states, and counties. Another valuable device is a line that passes through places having the same characteristic. For example, on a map of the United States a line may pass through all places having an average January temperature of 10°; another line, through places that have an average of 20°; another, 30°. Such temperature lines are called *isotherms*. On other maps, lines may pass through places having the same annual rainfall, same elevation above sea level, or same relative humidity. Lines may be drawn to show the boundary line between forest and prairie or between desert and humid land.

Relief maps show elevation of the land above sea level. Various methods are employed to show relief, some of them (1) by colors, such as green for plains, light brown for low mountains, dark brown for high mountains, (2) some by shading one side of a mountain range or hill (Fig. 170), (3) by hachures (tiny lines that show hill and valley slopes), and (4) by contour lines. Relief maps are of particular value in studying the surface features of the land, in laying out railroads and highways, in solving drainage and irrigation problems, and in explaining rainfall characteristics of certain regions.

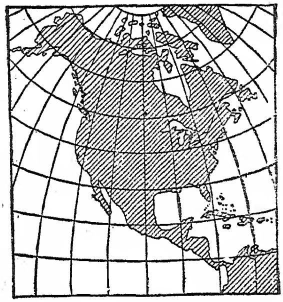


Fig. 167.—A polyconic projection.

Contour maps are probably the most valuable of relief maps because of their greater accuracy in showing elevation. A *contour line* is one that passes through places having the same elevation above sea level. The *contour interval* is the vertical distance between two adjacent contour lines. The idea of contour lines, their spacing, and their irregularities may be made clear by a simple illustration. In an open tank one may mold an oval mound of wax $6\frac{1}{2}$ inches high, steeply sloping at one end and gently sloping at the other. If 6 inches of water is permitted to flow into the tank, only $\frac{1}{2}$ inch of the mound will protrude. With a sharp point the position of the edge of the water upon the wax may be marked, and then the water level may be lowered by 1-inch stages, and the position of each stage marked on the surface of the wax. The marks made will now appear as contour lines on the wax mound, the lowest being everywhere 1 inch above the bottom of the tank, the next 2 inches, and so on to the sixth, as in Fig. 171*A*. If the mound is viewed from directly above, the arrangement of the lines will be that of Fig. 171*B*. This is the appearance of a contour map. It will be noted that, where the slope of the mount is steep, the contour lines are close together and that they are more widely spaced as the slope becomes more gentle. In this illustration the contour interval is 1 inch.

Fig. 168.—Bonne's projection.

The topographic maps of the U.S. Geological Survey depend wholly upon contour lines to produce the effect of surface relief. They are printed in either three or four colors, each having a restricted meaning. In black are shown those features in the surveyed area which may be classed as *culture, i.e.*, those which have human origin. In this color are roads, houses, towns, place names, bound-

ary lines, and parallels and meridians. In blue are printed all water features, both natural and man-made, such as canals, streams, marshes, millponds, lakes, or seas. The various classes of such features are distinguished by appropriate symbols in blue. In green, if that color is shown, are areas covered by timber or woodland. This feature is shown on a small number of the

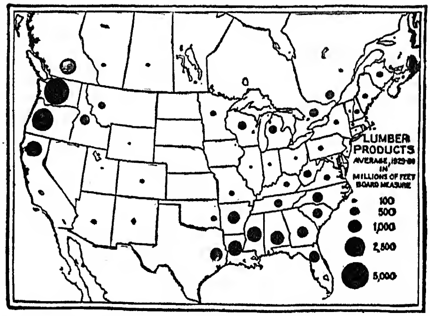


FIG. 169.—A cartogram that shows the distribution of a manufacturing industry by dots of graduated sizes.

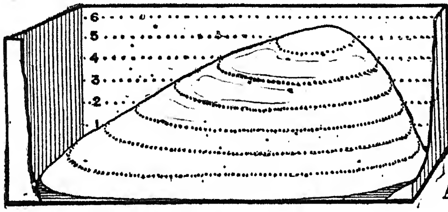
FIG. 170.—The wall map of Switzerland by Kümmerly and Frey, of which the foregoing is a photographic reproduction, is printed in subdued colors and is an example of the best in maps that simulate modeled relief.

published maps only. The contour lines and other symbols relating to the relative elevation of the land surface are shown in brown.

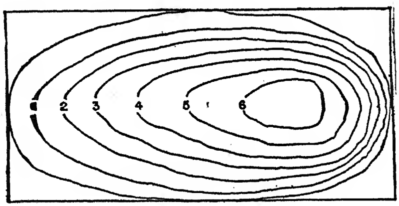
Each map is provided with a place title and with parallels and meridians that indicate its exact location and extent. The scale and contour intervals are printed on each map. It is important that these be noted carefully when beginning the study of a new sheet. Contour lines express the elevation of the land, in feet, above mean sea level. Every fifth contour line is heavy and numbered. In each surveyed area a few carefully measured points are given

permanent markers in the form of numbered metal posts called *bench marks.* These are indicated on the map by the letters *B.M.*, and the exact elevation of each one is given, printed in black.

The standard United States topographic sheet includes a quadrangle of 0°15′ of latitude and 0°15′ longitude. It is printed at a scale of 1/62,500, or approximately 1 inch to 1 mile. Some are drawn on different scales which are explained on the back of the map. The contour intervals employed usually



A



B

FIG. 171.

are 10, 20, 50, or 100 feet. On maps of extremely flat land an interval of 5 feet may be used; on maps of rugged mountains the interval is usually 100 feet or more.

Many relief features of the earth are discussed in this book. They can be better understood if they are illustrated by the use of topographic quadrangles. A list of specific quadrangles illustrating certain landforms is given in Appendix E.

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Appendix E. Useful Data and Tables

Avoirdupois Weight

16 drams	=	1 ounce (oz.)
16 ounces	=	1 pound (lb.)
7,000 grains	=	1 pound
100 pounds	=	1 hundredweight (cwt.)
2,000 pounds	=	1 ton
2,240 pounds	=	1 long ton

Metric Weight

1 gram	=	1,000 milligrams
1 gram	=	100 centigrams
1 gram	=	10 decigrams
10 grams	=	1 decagram
100 grams	=	1 hectogram
1,000 grams	=	1 kilogram

1 pound	=	.45 kilogram
1 kilogram	=	2.20 pounds
1 gram	=	15.43 grains
1 metric ton	=	1,000 kilograms = 2,204 pounds

Linear Measure

12 inches	=	1 foot
3 feet	=	1 yard
16½ feet	=	1 rod
40 rods	=	1 furlong
5,280 feet	=	1 statute mile
6,080 feet	=	1 nautical mile

Metric Linear

1 meter	=	1,000 millimeters
1 meter	=	100 centimeters
1 meter	=	10 decimeters
10 meters	=	1 decameter
100 meters	=	1 hectometer
1,000 meters	=	1 kilometer

1 meter	=	39.37 inches
1 mile	=	1.60 kilometers
1 kilometer	=	0.62 mile

Time

60 seconds	=	1 minute
60 minutes	=	1 hour
24 hours	=	1 day
365 days	=	1 year

Longitude and Latitude

60 seconds (″)	=	1 minute (′)
60 minutes (′)	=	1 degree (°)
Highest longitude	=	180°
Highest latitude	=	90°

Atmospheric Pressure

1 inch	=	25.40 millimeters	=	33.86 millibars
1 millimeter	=	0.039 inch	=	1.33 millibars
1 millibar	=	0.029 inch	=	0.75 millimeter

Length of Longest Rivers

Missouri-Mississippi	4,221 miles
Nile	4,000 miles
Amazon	3,900 miles
Ob	3,200 miles
Yangtze	3,100 miles
Congo	2,900 miles
Amur	2,900 miles

High Mountains

Everest	29,141 feet
Godwin Austen	28,251 feet
Aconcagua	22,830 feet
McKinley	20,300 feet
Kilimanjaro	19,324 feet
Elbrus	18,468 feet
Whitney	14,500 feet
Pikes Peak	14,110 feet

THE USE OF MILLIBARS[1]

Mb.	*Inches*	*Mb.*	*Inches*	*Mb.*	*Inches*	*Mb.*	*Inches*	*Mb.*	*Inches*	*Mb.*	*Inches*
940	27.76	960	28.35	980	28.94	1000	29.53	1020	30.12	1040	30.71
941	27.79	961	28.38	981	28.97	1001	29.56	1021	30.15	1041	30.74
942	27.82	962	28.41	982	29.00	1002	29.59	1022	30.18	1042	30.77
943	27.85	963	28.44	983	29.03	1003	29.62	1023	30.21	1043	30.80
944	27.88	964	28.47	984	29.06	1004	29.65	1024	30.24	1044	30.83
945	27.91	965	28.50	985	29.09	1005	29.68	1025	30.27	1045	30.86
946	27.94	966	28.53	986	29.12	1006	29.71	1026	30.30	1046	30.89
947	27.96	967	28.56	987	29.15	1007	29.74	1027	30.33	1047	30.92
948	27.99	968	28.58	988	29.18	1008	29.77	1028	30.36	1048	30.95
949	28.02	969	28.61	989	29.21	1009	29.80	1029	30.39	1049	30.98
950	28.05	970	28.64	990	29.23	1010	29.83	1030	30.42	1050	31.01
951	28.08	971	28.67	991	29.26	1011	29.85	1031	30.45	1051	31.04
952	28.11	972	28.70	992	29.29	1012	29.88	1032	30.47	1052	31.07
953	28.14	973	28.73	993	29.32	1013	29.91	1033	30.50	1053	31.10
954	28.17	974	28.76	994	29.35	1014	29.94	1034	30.53	1054	31.12
955	28.20	975	28.79	995	29.38	1015	29.97	1035	30.56	1055	31.15
956	28.23	976	28.82	996	29.41	1016	30.00	1036	30.59	1056	31.18
957	28.26	977	28.85	997	29.44	1017	30.03	1037	30.62	1057	31.21
958	28.29	978	28.88	998	29.47	1018	30.06	1038	30.65	1058	31.24
959	28.32	979	28.91	999	29.50	1019	30.09	1039	30.68	1059	31.27

[1] Courtesy of U.S. Department of Commerce, Weather Bureau.

The daily weather service is based upon weather reports from hundreds of widespread observations over land and sea. Many of these reports include not only the surface weather observations, but also aerological observations which are extremely valuable in determining the amount of moisture and other elements in the atmosphere involved in the production of rain and storms. The accuracy of weather forecasts and the value of the daily weather service to the public depend in large measure upon having these widespread reports, not only from the United States, but also from adjoining countries like Canada and Mexico, and from contiguous ocean areas.

Atmospheric pressure is one of the important elements in these weather reports. In earlier years it was customary to express atmospheric pressure in inches denoting height of the mercury column in the barometer. Since the inch is a unit of length and not a unit of pressure, the use of inches for expressing atmospheric pressure is unsatisfactory for modern purposes. Several years ago the millibar, which is the standard unit of pressure, was adopted for aerological observations, and since then its advantages have resulted in its adoption by nearly all countries for use in expressing barometric observations taken on ships at sea as well as at regular weather stations on land.

Because of the delay incident to converting millibars into inches, with the increasing number of weather reports from ships at sea and from Canada and other countries, the Weather Bureau on July 1, 1939, adopted the numeral

code which uses millibars, and began publishing these units on its Washington Weather Map. This permits speedier handling of reports and greater accuracy in analyzing weather situations for the purpose of issuing weather maps, forecasts, and advices. Since January 1, 1940, isobars on all published weather maps have been labeled in millibars instead of inches.

It is not difficult to become accustomed to the use of the absolute unit, the millibar, in speaking of atmospheric pressure. It should be remembered that 1015.9 millibars equal 30.00 inches of mercury; 1 millibar equals approximately $\frac{1}{300}$ inch (0.0295). One-tenth inch of mercury equals 3.4 millibars, approximately.

The appearance of the published weather map is not significantly changed by use of the millibar system of pressure values. Isobars are drawn for each interval of 3 millibars of pressure variation, which closely corresponds to the interval of $\frac{1}{10}$ inch as heretofore used.

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